Electropalatographic Study of Speech Sound Errors in Adults with Acquired Aphasia

Thesis

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ELECTROPALATOGRAPHIC STUDY OF SPEECH SOUND ERRORS IN ADULTS WITH ACQUIRED APHASIA

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Abstract

Traditionally speech errors in adults with acquired aphasia have been described as either apraxic errors, characteristic of anterior lesions in the cerebral cortex affecting areas such as Broca's area, or phonemic paraphasic errors due to posterior lesions in areas such as Wernicke's area. However, studies have reported overlap in the descriptions of apraxic and phonemic paraphasic errors despite the assumption that these errors arise from different levels in the speech planning and execution process. For example, phonemic substitutions are associated with both types of error. Part of the problem is due to difficulties in identifying the precise nature and source of the errors which cannot be resolved by auditory perceptual judgments alone.

This study investigates, by means of electropalatography (EPG), the location and timing of contact patterns produced by ten adults with acquired aphasia. The subjects were variously diagnosed by traditional classification as Broca's aphasic with or without apraxia, conduction and anomic. These subjects variously demonstrated atypical patterns when compared to ten control speakers such as: increased temporal and/or spatial variability; specific difficulties in the sequencing and timing of two adjacent lingual consonants; and the presence of intrusive lingual/palatal contact patterns. These errors were usually undetected through auditory analysis. The atypical patterns were not associated uniquely with a particular aphasic syndrome but were subject specific and often related to the site of the lesion within the brain, for example, the basal ganglia. Both subjects diagnosed with apraxia of speech and those with phonemic paraphasia produced the EPG patterns noted above.

The EPG data provided insights into the nature and origins of errors such as substitutions which were unavailable from auditory-based analysis. Many of these error patterns could be accounted for by modification to Dell's model of spreading activation (Dell, 1980, 1985, 1986, 1990).

The results have important implications for therapeutic intervention since accurate diagnosis is crucial for effective intervention.

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Chapter 1

1. Introduction

1.1 Terminology

This thesis aims to investigate the nature and origins of speech sound errors in adults with acquired aphasia. This has been an area of controversy in part due to terminological confusion which has spanned many decades.

Darley, Aronson and Brown (1975) produced a definition and description of apraxia of speech which distinguished it from other acquired neurogenic speech disorders in an attempt to resolve some of the confusion. They considered apraxia of speech to be "a disorder of motor speech programming manifested primarily by errors in articulation" (p.267) following a left cerebral hemisphere injury to the anterior portion of the brain. These errors could not be explained by paralysis, weakness or incoordination of the speech musculature which differentiated apraxia of speech from the dysarthrias. This description of apraxia of speech parallels Broca's original description of aphemia (1861). The term applied to all speech errors not considered to be dysarthric in origin. It proposed that apraxia of speech was an articulatory problem which was completely separate from aphasia. For Darley et al. (1975) aphasia affected syntax and semantics and not the production of speech sounds. They summarize apraxia of speech as follows:

> "Apraxia of speech is characterized by highly variable articulation errors embedded in a pattern of speech made slow and effortful by trial-and-error gropings for the desired articulatory postures. The off-target productions are usually complications of articulatory performance, that is, substitutions (many of them unrelated to the target phoneme), additions, repetitions, and prolongations. Less frequently the errors are simplifications, that is, distortions and omissions. Errors are most often on consonants occurring initially in words, predominantly on those phonemes and clusters of phonemes requiring more complex muscular adjustment. Errors are exacerbated by increase in length of word and the linguistic and psychologic "weight" of a word in the sentence. They are not significantly influenced by auditory, visual, or instructional set variables. Islands of fluent, error-free speech highlight the marked discrepancy between efficient automatic-reactive productions and inefficient volitional-purposive productions." (p.267).

The opinion that all speech errors not considered dysarthric in nature were of the same origin is a view which has been opposed by many. Goodglass and Kaplan (1972) believe that there are "mutually exclusive classifications" (p.30) which separate the speech errors Darley et al. (1975) called apraxic. Goodglass and Kaplan (1972) distinguish between errors which are a result of an articulatory disorder and those which are due to disorganization of the linguistic system. The latter they term paraphasic errors which are defined as "the production of unintended syllables, words or phrases during the effort to speak ..... (and) characteristic of patients whose speech sounds are fluently uttered" (p.8). These paraphasic errors are further divided into literal (or phonemic) paraphasia, verbal paraphasia and extended jargon. In describing these literal paraphasias Goodglass and Kaplan (1972) state that "In spite of easy articulation of individual sounds, the patient produces syllables in the wrong order or distorts his words with unintended sounds...Some phonemic features (usually the vowels and the number of syllables) of the intended words are preserved" (p.8). Therefore, the literal paraphasias equate to the speech sound errors described by Darley et al. (1975).

Goodglass and Kaplan (1972) established a set of aphasic syndromes to assist in the classification of neurogenic speech disorders. They state that the "major subdivision among the aphasic syndromes is based on the character of the speech output" (p.54) which referred specifically to fluency. "Non-fluent" (p.54) speech was the result of lesions to the anterior cerebral cortex affecting areas such as Broca's area. It was thought that non-fluent aphasics made speech sound errors that were of an articulatory nature and characteristic of a Broca's aphasic. This resulted in the terms non-fluent and Broca's aphasia being used interchangeably. Patients whose lesions were posterior to the rolandic fissure were considered to demonstrate fluent speech. This was said to be typical of Wernicke's and conduction aphasics whose speech was characterized by phonemic paraphasic errors. Therefore the terms non-fluent and fluent were also used to describe the speech errors resulting from lesions to the anterior and posterior areas respectively.

There was much early support for the motoric/linguistic dichotomy which separated apraxic speech errors from paraphasic speech (Poncet, Degos, Deloche and Lecours, 1972; Canter, 1973; Burns and Canter, 1977; Blumstein, 1973; Lecours, 1975). Canter (1973) differentiated between a motor impairment, which he linked to Broca's aphasia, and a linguistic impairment which was associated with Wernicke's and conduction aphasics. The results from two studies which investigated the error patterns of these aphasic syndromes (Trost and Canter, 1974, Burns and Canter, 1977) suggested that these syndromes could be separated according to the type of speech sound errors they produced. Broca's aphasics presented with phoneme distortion errors which were absent in the speech of the Wernicke's and conduction aphasics who they described as paraphasic. Furthermore, the Broca's aphasics produced more errors of simplification compared to the paraphasic speakers who produced complications of the target structure. Therefore, for these writers, Broca's aphasia was synonymous with Darley et als. (1975) description of apraxia of speech (Goodglass and Kaplan, 1972; Canter, 1973, Trost and Canter, 1974; Burns and Canter, 1977).

Lebrun (1989) believed that apraxia of speech and Broca's aphasia could be differentiated according to the type and frequency of errors. He stated that both apraxic speakers (which he termed anarthric) and Broca's aphasic patients make phonemic paraphasic errors but that the apraxic's speech was characterized by anticipatory paraphasic errors compared to perseveratory errors produced by Broca's aphasics. Nespoulous, Lecours and Joanette (1982) also found error differences which separated apraxic and Broca's patients. They noted that Broca's aphasics replaced voiced plosives by homorganic voiceless plosives more often than those diagnosed as apraxic. Furthermore, Lebrun found that his apraxic subjects could perform metalinguistic tasks and were able to recognize their speech errors which the Broca's aphasics could not. This he took as evidence that the apraxic speakers retained phonological knowledge which was lost in Broca's aphasia. He states that "apraxia of speech really is what its name implies, a praxic disorder of articulation" (p.13).

Martin (1974) questioned the appropriateness of apraxia of speech as either a descriptive or explanatory label. He considered the term to be a reflection of an outdated dichotomous model of language functioning. Martin believed what Darley et al. (1975) called "apraxia of speech" was really a variety of aphasia resulting from an inability to select and combine linguistic units at the phonological level of speech production. Therefore, he did not believe that apraxia of speech was a separate disorder from aphasia.

1.2 The Study Of Speech Sound Errors In Acquired Neurogenic Disorders

Recent studies of speech sound errors produced by patients with acquired neurogenic disorders have been divided into three categories: speech errors as a result of a dysarthria; apraxic errors considered to be characteristic of anterior lesions in the cerebral cortex affecting areas such as Broca's; and phonemic paraphasic errors believed to be a result of posterior lesions in areas such as Wernicke's (Blumstein, Cooper, Zurif, and Caramazza, 1977; Blumstein, Cooper, Goodglass, Statlender and Gottlieb, 1980; Mackenzie, 1982; Shewan, Leeper, and Booth, 1984; Gandour and Dardarananda, 1984; Ryalls, 1986). However, the precise nature and origin of these errors is still a matter of controversy. Part of the problem lies in the nature of the data: very often the data consists of impressionistic auditory-based error counts which give unreliable information on the nature of errors such as substitutions. This thesis will contribute to the debate on speech errors in aphasia by investigating a range of aphasic syndromes as described by Goodglass and Kaplan (1972), including both non-fluent and fluent aphasics, using the instrumental technique of electropalatography. The subjects are variously diagnosed as Broca's with apraxia of speech, Broca's without apraxia of speech, conduction and anomic aphasics. Goodglass and Kaplan (1972) state that anomic aphasia is characterized by "the prominence of word-finding difficulties in the context of fluent grammatically well-formed speech" (p.61). They state that Wernicke's aphasics often evolve into anomic aphasics. Their auditory comprehension is considered to be intact and there is an absence of literal and verbal paraphasia.

This investigation intended to build on the knowledge from earlier studies and work towards a classification scheme for speech errors in acquired aphasia. The author shares the views of Babinski (1904) (quoted in Lebrun, 1989) that "Diagnostic errors result far more frequently from imperfect observation of the symptoms than from faulty interpretation of them" (p.16).

1.3 Research Questions

With this controversy in mind this thesis will address the following research questions:

1. What additional information does EPG bring to an auditory-based analysis?
2. Do the aphasic speakers demonstrate spatially normal lingual/palatal contact patterns?
3. Do the lingual/palatal articulations produced by aphasic speakers exhibit more temporal and spatial variability than normal speakers?
4. Do the aphasic group demonstrate specific differences in the sequencing and timing of the tongue tip/blade and tongue body in consonant sequences when compared to normal speakers?
5. Are specific error patterns characteristic of Apraxia of speech ?
6. Can traditional aphasia syndromes be separated by differences in error patterns and incidence of these?
7. How can the information gathered from an EPG investigation assist in identifying the level of impairment in speech production? What consequences does this have for models of speech production?

1.4 Outline Of The Thesis

A brief outline of the thesis is provided to assist the reader.

This opening chapter highlights the terminological confusion surrounding the field of speech sound errors in acquired aphasia and has introduced seven research questions which this thesis will address. The second chapter offers a detailed review of the literature covering observational, auditory-based and instrumental studies which are precursors of this investigation. Two distinctly different models of speech production are also outlined and are discussed in greater detail in Chapter 8 with relation to the data collected. Chapter 3 describes the method and includes test material, instrumentation and recording, data analysis and subject details. The methods of data analysis outlined are employed in three results chapters (Chapter 5, Chapter 6 and Chapter 7). Chapter 4 is a self contained auditory-based study which arose following initial analysis of the data. It looks in detail at the relationship between auditory-based impressions and instrumental analysis of the data for one aphasic speaker. Chapter 8 provides a discussion of the results in relation to the research questions proposed in Section 1.3. Implications for therapeutic intervention and suggestions for future related studies are proposed. In the final chapter conclusions are drawn regarding the distinction between motoric and linguistic based speech sound errors.

Chapter 2

2. Review Of The Literature

2.1 *Historical Issues*

The study of acquired neurogenic speech disorders has been the subject of debate since the early nineteenth century. Approaches to this area have changed during this time, from early localizationist views to hierarchical models of speech production. Despite almost two centuries of examination and questioning by researchers from a variety of backgrounds, the origin of speech disorders following brain damage continues to be an area of much disagreement. From early clinical observational case studies and associated post-mortems to the latest instrumental techniques, there are still a multitude of questions in need of answering and misconceptions to be erased. The following will highlight the most significant advances and changes in this field of research which are of relevance to this thesis.

2.1.1 Cerebral localization

The scientific study of acquired language disorders probably originated in the early part of the nineteenth century. At this time researchers were interested in clinically derived single case studies of the language-brain relationships. These localizationists looked specifically at the operation of centres and connections and not psychological or neurological models. As early as 1825, Bouillaud was concerned with speech disorders and language localization. This date marked the start of differentiation between the formulation of thought symbolized by words and the execution or articulation of these.

In his first publication, Bouillaud (1825a) put forward the concept of different faculties associated with the production of speech. He suggested that there were two faculties, one for putting thoughts into words and retaining these in memory and a separate faculty concerned with the articulation of these words. The latter was divided into an executive element and a coordinating element which together made up "l'organe législateur de la parole". But more than this, Bouillaud linked these faculties to areas of the brain. The faculty for articulating words was situated in the white matter of the frontal lobes. He was less specific in the location of the other faculty choosing only to suggest that it may be in the grey matter.

These early views on localization were revised and published in a book by Bouillaud (1825b). In this he altered his views stating that the transference of thoughts into words was now the process executed in the frontal lobes. The faculty for articulating words received no mention in his revision. However, in 1826 (cited in MacMahon, 1981) he published another paper in which he reverted back to his original ideas on language localization. Following this confusion and contradiction of opinion a period of ten years elapsed before he made any further public comment concerning localization. At this time he believed speech production had not two but three distinct phases: initially ideas are put into a verbal form; then the necessary commands are coordinated; finally, the two are sent along particular routes to the organs of speech.

Following this reaffirmation on the localization of language there was a period of quiet before a renewed interest in neurolinguistics began in the 1860's. This was established with the work of Paul Broca who was aware of the need for a neurolinguistic theory if speech production was to be properly understood. According to MacMahon (1981) there is much misunderstanding surrounding the work of Broca because his work has frequently been misquoted and extended by others. MacMahon has studied the original scripts and tried to understand exactly what Broca was saying. It is from MacMahon's thesis (1981) that the following comments concerning Broca and his contribution to the field of neurolinguistics are taken.

Broca was first and foremost a physician and a surgeon who had published in anatomy and anthropology. But he was also a linguist with a particular interest in Breton and Basque. He was very thorough in his investigations, checking all data carefully and revising his views as the clinical data changed. Whilst he never published a book, he produced a number of case reports introducing new data as it emerged. Broca's first case study, frequently quoted in the literature, concerns a patient called Leborgne, often referred to as Tan Tan since this was the extent of his verbal output. A post mortem carried out following the death of Leborgne revealed that almost all of the left frontal lobe had become softened. Broca believed that a lesion in this area was the cause of the difficulties in speech production that his patient had suffered. This exactly coincided with the views of Bouillaud some 35 years earlier. Broca realized that he needed to be more precise and developed his first model of speech production (Figure 2-1). Through this he initiated the idea of the progression from one part of the model to another. He visualized the process of language involving five stages. The first stage (1) was concerned with ideation. The second (2) involved the operation of "la faculté générale du langage", a store of words underlying all modalities. Within this faculty was "la faculté du langage articulé" which specifically dealt with muscular movements for speech. The third stage (3) was concerned with the movement of information along the motor nerves. The fourth stage (4) involved the movement of the muscles of the speech organs and the final stage (5) was the resulting effect, namely "le langage". This theoretical framework was used to explain the condition of his patient Tan Tan. He proposed that he had no loss for the memory of words but that his problems were because he could not coordinate the necessary muscular movements for speech, a process which he believed was situated in "la faculté du langage articulé". In hindsight, it seems that Broca was describing something very specific which would appear to equate to our understanding of the term apraxia of speech. In August 1861 he used the word "aphemié" (aphemia) to describe Leborgne's linguistic condition. He was said to be aphemic since his "faculté générale du langage" remained intact, his hearing was normal, none of the speech musculature was paralyzed and his comprehension was normal. What he lacked was "la faculté d'articuler les mots". Therefore, Broca's original description of aphemia was very specific. He was, however, aware that not all aphemics presented alike but instead he identified three types: those patients who could produce a short series of syllables; those who were unable to produce anything audible when attempting to speak; and those able to produce single words and sometimes a second when they were angry.

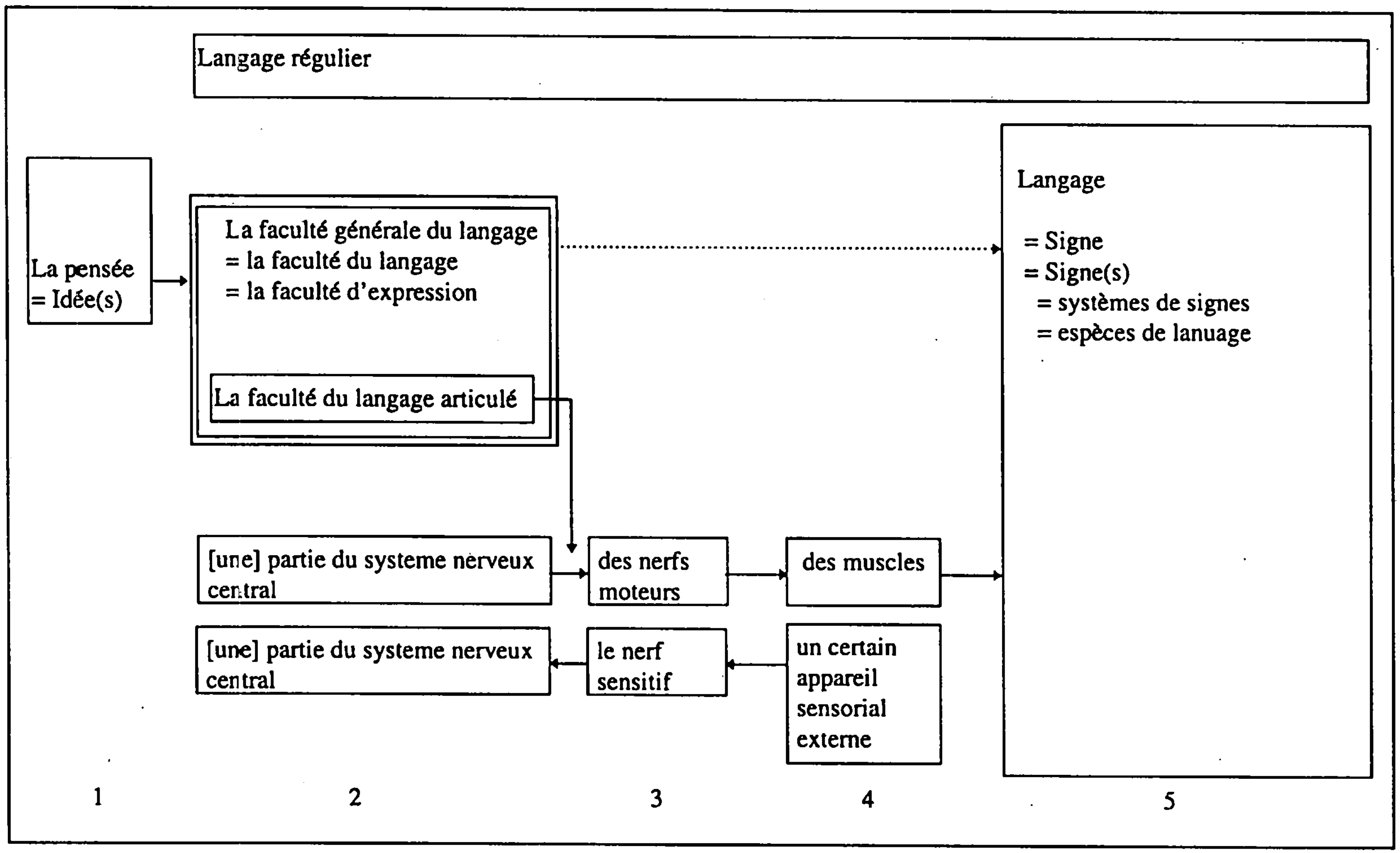


Figure 2-1: Broca's first model of speech production (taken from MacMahon, 1981)

Broca's views on aphemia were to change as he studied more patients. His description of the disorder was extended and became broader based. In 1864(a) Broca redefined aphemia to include disturbances in the faculty combining words to create phrases. By this MacMahon suggests that he was referring to some kind of syntactic breakdown. He began to suggest that other "especes de langage" may be lost, presumably reading and writing. But if other modalities are involved then it seems likely that "la faculté générale du langage" itself is affected. The distinction between "la faculté du langage articulé" and "la faculté générale du langage" was now less precise. However, in another paper (1864b) Broca returned to his earlier standard definition, making a clear distinction between the two faculties. These fairly gross revisions resulted in much confusion with regards to definition within the field of neurolinguistics. In 1869, he published in La Tribune Médicale (1869a), a leading French periodical. It appears that this was a last attempt to clear up the confusion which had arisen following his original definition in 1861. In this he suggested that there were four different speech pathologies resulting from brain damage:

1. "Alogie" - This represented a disturbance of intellectual faculties.
2. "Amnésie verbale" - The relation between ideas and words has been lost due to a loss of "memoire des mots".
3. "Aphemié" - A breakdown at the level of "la faculté du langage articulé".
4. "Alalie mécanique" - This described the condition where no physical power could reach the muscles due to a mechanical defect in the nerves or parts of the brain that send the command.

Whilst Broca realized that there could be different degrees of severity for all of these he never suggested that there could be mixed types.

During the period 1861 to 1869, Broca's views on the areas of the brain responsible for aphemia also changed quite dramatically. Originally he supported the views of Bouillaud, that language was situated in the frontal lobes, specifically the left. By July 1863 he began questioning the role of the parietal lobe and in 1864 the right hemisphere came under the spotlight. In 1868, Broca became concerned with explaining how damage in the insula could produce the same aphemic effects as damage to the left inferior frontal gyrus. In his last statement concerning brain localization (1868c) he concluded that aphemia included the posterior half of the left inferior frontal gyrus, the insula, the "circonvolution d'enceinte" and the right hemisphere.

Broca's final comments concerning aphemia in 1869(b) were very specific. The condition referred purely to the coordination of muscular movements required for speech which is similar to Darley, Aronson and Brown's (1975) description of apraxia of speech (hereafter referred to as AOS).

Broca's description of "aphémie" has often been misquoted and misunderstood. MacMahon (1981) suggests two main causes for this. Trousseau, another French researcher, objected to the term on etymological grounds. He preferred to call the condition that Broca described "aphasié", but in doing so also extended its meaning to include verbal amnesia, transitory cerebral dysfunction and cases where no certain diagnosis could be made. In 1865 Trousseau wrote a book on aphasia. He used this terminology instead of "aphémie" but included in his description both "la faculté générale du langage" and "la faculté du langage articulé". Therefore, Trousseau's definition encompassed a wider meaning for "aphemié" than Broca's original description since Trousseau was also concerned with lexical, grammatical, kinaesthetic and intellectual aspects of speech pathologies following brain damage. This is different to the original disorder that Broca was describing.

MacMahon (1981) also suggests that inaccurate translation of Broca's work into the British Isles also lead to a misunderstanding of Broca's "aphemié". In the British Medical Journal "aphemié" was synonymous with "aphasia" which was synonymous with "loss of voice"! So the original definition was lost and Broca's aphasia as described by Goodglass and Kaplan (1972) is far removed from the original work of Broca.

2.1.2 The advent of neurolinguistic models

Several researchers were reluctant to accept the concept of cortical centres for components of language. Instead, many began to believe that the whole brain or at least large portions of it were responsible for the individual task of language functioning. This lead to the appearance of neurolinguistic models. Caplan (1987), in his discussion of process models, suggests that Luria (1947) put forward the ".... first, most comprehensive, and most influential neurolinguistic process model" (p.121). Luria believed that Broca's ideas were limiting because they ".... necessitated drawing a sharp distinction between disturbances of the motor images of words and all other sensory and motor disorders and required that this psychological phenomenon be localized within a narrow region of the brain" (1966 p.184-185). Instead, Luria believed that there were close links between areas of the brain responsible for sensory motor functions and the linguistic and other intellectual functions for which these areas were also responsible. Caplan (1987) states that for Luria "parallels between motor and linguistic disturbances are not accidental" (p.131) but that these areas of the brain have the same basic functions.

2.2 Speech Sound Errors In Neurogenic Speech Disorders

This thesis is interested in the speech sound errors following cerebrovascular accident (CVA). Specifically, it focuses on those errors traditionally described as typical of AOS and phonemic paraphasic errors. These are separate from the errors produced by dysarthric patients whose speech sound problems arise from a generalized weakening of the speech musculature (Darley et al., 1975). Attempts to separate AOS and phonemic paraphasia on the grounds of the type of error predominating has added to the confusion in defining these disorders.

2.2.1 Substitutions

One of the problems in trying to arrive at a differential diagnosis is that both AOS and those felt to be demonstrating phonemic paraphasic errors make what appear auditorily to be errors of substitution. Itoh and Sasanuma (1984) suggest that this is the most common speech error in AOS. Whilst this has been generally accepted it should be noted that recent research has questioned this. Square, Darley and Sommers (1982) state that distortions are the "predominant phonetic error" in AOS. Similarly Odell, McNeil, Rosenbek and Hunter (1990a) found that distortions were the most frequent error type produced by the 4 pure apraxic subjects they investigated. Rosenbek and McNeil (1991) advocate that studies involving broad phonetic transcriptions have lead to data confirming the views of Darley et al. (1975) that AOS is characterized by substitutions and dysarthria by distortions. They suggest that we should set aside these premises until more data is available from a larger number of subjects and several levels of analysis, for example, perceptual, acoustic and kinematic.

An interesting question is the origin of the substitution. Recent research has suggested that there are two distinct types of substitution errors which cannot be separated through auditory judgment alone. The substitutions could, in theory, arise either from motoric or linguistic impairments. As early as 1966, De

Renzi, Pieczuro and Vignolo wrote "It is hard to decide if the substitutions of voiced consonantal sounds (e.g., b, v, g) by the corresponding voiceless consonants (p, f, k respectively) are due to the wrong choice of phonemes .... or to lack of synergy of the vocal cord with the muscles of articulation" (p.55) (quoted in Kent and Rosenbek, 1983). The comment made by De Renzi et al. (1966) questions whether the noted substitution is the direct result of a motoric or linguistic deficit. Similarly, Hardcastle and Edwards (1992) discuss the interpretations of a word initial /t/ heard as a [k] in the word "tick". They suggest that the perceived substitution could have more than one explanation relating to different levels of processing. Incorrect phoneme selection, but correct vocal tract configuration for the substituted phoneme would suggest an error of phoneme selection occurring at a higher level of processing than a motoric phonetic error. Alternatively, the [k] could have been executed prematurely, either before the /t/ or overlapping temporally with it. The resulting double articulation may sound more like a /k/ than a /t/. This would suggest a problem with the sequencing of articulatory gestures, a motoric deficit. These explanations relate to two hypothetically different neural functions.

The following sections review the auditory-based and instrumental investigations which have attempted to highlight the salient and diagnostic aspects of aphasic and apraxic speech. It is important to identify the errors which arise from acquired neurogenic speech disorders if we are to develop more accurate models of speech production. The identification of errors will allow researchers to speculate on the source of the error.

2.3 Auditory-Based Analyses

Much of the early work concerning the speech of aphasic patients centred around auditory-based studies. A major advantage of such investigations are the non-invasive methods employed by the experimenter. However, the value of these studies has been questioned. Whilst Canter, Trost and Burns (1985) believed that "phonological analysis emerges as a tool sensitive to many of the differences" (p.217) in the speech patterns of anterior and posterior aphasics others strongly disagree. Ziegler and Hoole (1989) state that there is a psychological component associated with auditory analysis which causes the listener to favour "categorical" (paraphasic) errors over "non-categorical" (distortions). Furthermore, research replicating earlier studies has often resulted in conflicting findings and these studies can suffer from methodological restrictions (e.g. number of subjects, broad phonetic transcriptions) and differences such that it can be argued that they are not replicating earlier work.

The research that evolved immediately following Paul Broca's description of aphasia (1869b) was an unsystematic study of the phonological errors of aphasic patients. There was no notion of the phonological system being governed by linguistic organisation. It was post 1925 when systematic studies on the nature of the errors developed and similarities in the types of errors made by aphasics were identified. An underlying uniformity was found that could be characterized by Jakobson, Halle and Fant's distinctive feature framework (1962).

Blumstein (1973), by means of perceptual-based phonological analysis, compared the speech of 6 Broca's aphasics with 6 Wernicke's and 5 conduction aphasic speakers (considered to be paraphasic). The study was governed by three aims: to systematically characterize phonological patterns by identifying significant error patterns in aphasic speech; to explore the relationship between these patterns of error and brain pathology; and to test theoretical linguistic assumptions based on her findings. Whilst she found that the Broca's aphasics made more articulatory errors (defined as simplification or addition), the nature of these did not discriminate them from phonemic paraphasias. She concluded that "the phonological analysis of aphasic speech revealed no consistent differences among the 3 aphasic groups studied" (p.73) and that "the phonological errors characteristic of aphasic speech reflect a systematic disorganization of phonology independent of a particular lesion site" (p.47). She also noted that phoneme substitutions were the most frequent type of error, commonly involving one distinctive feature ("teams" → [kimz], "time" → [taɪn], examples from Blumstein, 1973). A similar study by Canter et al. (1985) failed to replicate these earlier findings. A phonological analysis of 20 aphasic speakers (10 Broca's, 5 Wernicke's and 5 conduction aphasics) revealed significant differences between the apraxic speakers (who they considered to be Broca's aphasics) and those with phonemic paraphasic speech with regard to distribution of error types. The subjects could be separated by frequency of errors occurring in word initial and word final position and the relative difficulty of different classes of phonemic segments. The results from the study were taken as support for a division between a disruption in the retrieval of phonological word patterns in paraphasic speakers and a disturbance in encoding phonological patterns in apraxic speech. In their discussion Canter et al. (1985) state "the clinical differentiation between apraxia of speech and phonemic paraphasia thus seems eminently sound" (p.217). These findings were used to support their claim that perceptual phonological analysis was a sensitive method for examining the speech of aphasics. However, they were not studying pure AOS but Broca's aphasics with AOS and therefore these patients presumably had some linguistic involvement. The validity of the study is also questioned since there is no information on who performed the narrow phonetic transcriptions although they do state that intra-subject reliability was assessed.

Mackenzie (1982) also proposed that "aphasic subjects whose speech contained articulatory-phonemic errors are not a homogenous group phonetically". Instead she believed that aphasics could be separated into fluent and non-fluent aphasic syndromes on the basis of speech production. She classified the errors produced by the aphasic speakers into the following categories: substitution; omission; distortion; environmental replacement; addition; compound; and replacement by reduction. For a critical review of this classification see Section 5.1.2. Mackenzie then compared the errors produced by 48 aphasics and found that they were indeed not a "homogenous group phonologically" (p.28) but that they could be characterized by errors relating to the production of speech sounds and those connected with linguistic disruption. These she called "aphasic articulatory deficit" and "aphasic phonological deficit" (p.43) respectively.

Miller (1995) devised a more comprehensive and thorough taxonomy based on perceptual identification of speech errors to differentiate thirty neurologically disordered speakers variously diagnosed as spastic dysarthric, speech dyspraxic and phonemic paraphasic without dysphasia, and speech dyspraxic and phonemic paraphasic with dysphasia. A narrow phonetic transcription tried to place the errors into twenty seven predetermined error types. However, according to Miller himself, this expanded taxonomy did not provide any additional diagnostically useful information and many of the categories were redundant or had to be collapsed (e.g. anticipatory, perseveratory and transposition derailments became one category).

A study by Odell, McNeil, Rosenbek and Hunter (1991) analysed the perceptual characteristics of vowel production and prosody in apraxic, conduction aphasia and ataxic dysarthric speakers through narrow phonetic transcriptions and prosodic judgments of single word imitations. They concluded that effective differentiation between the disorders could be made with the diagnosis relating to the locus of error, type of error and the syllabic properties of the words.

Whilst there have been several perceptual studies concerning the speech production of aphasic patients, the limitations of these must be recognised. All the studies reviewed here, with the exception of Mackenzie (1982) are limited in the number of subjects investigated and it is not clear as to whether the same group of subjects are being investigated due to confused diagnostic terminology. For example some researchers appear to use the terms AOS and Broca's aphasia interchangeably (Canter et al., 1985) whereas for others they are different categories. Furthermore, in the study of AOS it is not always clear if there is any aphasic involvement. Results and conclusions from one study are often not replicated in later studies, for example the results of Blumstein (1973) are contradicted by Canter et al. (1985). Notwithstanding methodological drawbacks, perceptual studies which employ the judgments of listeners are indirect measures of speech production. From them we do not learn about speech behaviours but instead the acoustic end-products of the behaviour and the interaction of these with the listener's perceptual system. The perceptual studies are unable to identify the differing underlying mechanisms which may be impaired. Furthermore, subtle changes not apparent to the listener such as VOT values that fall within the area of separation for a voiced and voiced stop cognate, are lost. So it would appear that whilst many have suggested the separation of AOS and phonemic paraphasia is possible through perceptual studies the reliability of these judgments is entirely questionable, and that perhaps Canter et al. (1985) were overly optimistic in their view that "phonological analysis emerges as a tool sensitive to many of the differences" (p.217).

Buckingham and Yule (1987) suggest that the aphasic error patterns reported from these types of investigation may tell us more about the perceptual processes on the part of the listener rather than the production failure of the speaker. By this they suggest that we are biased towards categorical errors. The adult human ear is not able to detect fine differences in the speech signal. VOT productions which fall between the voiced and voiceless parameters for a pair of stop cognates are therefore assigned to one or the other since we do not have an alternative category in English available to us.

One of the other major criticisms of the perceptual studies concerns reliability of perceptual judgments. There is often little information available regarding who the transcribers were or the inter-transcriber reliability. For example, Blumstein (1973) states that phonological errors were "transcribed using the International Phonetic Alphabet" (p.36) but no other detail is given. Other studies state that there was only one listener. In such studies the validity of the transcriptions must be questioned and more detail on the training this transcriber has received should be made available.

2.3.1 Summary of findings from auditory-based analyses

The main findings from the perceptual studies are summarized below and in Table 2-1.

1. The results from one study often conflict with those from another. This is probably a direct result of methodological differences and in particular subject selection.

2. Blumstein (1973) suggested that phonological analysis reveals that there are no consistent differences between traditional aphasic syndromes but Mackenzie (1982), Canter et al. (1985) and Odell et al. (1991) believe that perceptual analysis can separate the aphasic syndromes with respect to the errors they produce. The different errors relate to motoric or linguistic disruption.

3. Phonemic errors are the most frequent error type for all aphasic speakers and these typically involve one distinctive feature (Blumstein, 1973).

Authors	Date	Study	Main findings
Blumstein	1973	Perceptual phonological analysis of Broca's, Wernicke's and conduction aphasics	No consistent differences amongst the 3 groups of aphasics revealed by phonological analysis
Canter et al.	1985	Perceptual phonological analysis of Broca's, Wernicke's and conduction aphasics	Subjects separated by frequency of errors occurring in WI or WF position and difficulty of different classes of phonemic segments
Mackenzie	1982	Comparison of the speech errors produced by 48 fluent and non-fluent aphasics	Not a homogenous group phonologically. Could be separated by production errors and linguistic errors
Odell et al.	1991	Perceptual characteristics of vowels and prosody for AOS, conduction aphasic and ataxic dysarthric. Analysed using narrow phonetic transcriptions and prosodic judgments	Able to differentiate the disorders by 1. locus of error 2. type of error 3. syllabic properties of the word
Miller	1995	Comparison of the speech errors of 30 neurologically disordered speakers	Extended taxonomy did not add diagnostically useful information

Table 2-1: Summary of the main auditory-based studies and their findings.

2.4 Instrumental Investigations

The limitations of an auditory-based analysis have lead to the development of instrumental techniques capable of investigating physiological, acoustic and aerodynamic aspects of the speech signal. Whilst these have the advantage of being less subjective they are not without limitations themselves. For example, acoustic studies focus on the end product of an articulatory event and therefore are not directly involved with the measurement of the speech apparatus itself. Browman (1995) states that "acoustic data alone cannot be used to determine what is being controlled" (p.336) and suggests that an acoustic signal may be more discrete than the articulation itself. However, other instrumental studies, such as those involving movement tracking devices, are disadvantaged because they are often accused of being invasive. Despite these limitations there have been numerous instrumental studies investigating acquired neurogenic speech disorders which have provided important and relevant data.

Much research surrounding the controversy of phonetic versus phonemic disorders has involved the study of acoustic patterns. The reasoning behind these investigations arises from the belief that if patterns deviate from the normal then specifying and quantifying the nature of the deviation will determine what articulatory configurations could produce such acoustic patterns. Kent and Rosenbek (1983) attempted to identify and describe the acoustic correlates of articulatory disturbance in 7 apraxic subjects. The subjects were said to be free from severe aphasic impairments and were not considered to be Broca's aphasics since they did not demonstrate agrammatic speech (considered to be a diagnostic feature by Kent and Rosenbek). In addition to wide band (300Hz) and narrow band (45Hz) spectrographic analysis, they used intensity and fundamental frequency displays (f_o). Through their analysis they identified several aspects of the speech signal which they felt characterized apraxic speech: slow speaking rates with prolongation of transitions; steady states; intersyllabic pauses; reduced intensity variation; slow and inaccurate movement of the articulators; incoordination of voicing with other articulations; initiation difficulties; and errors of selection or sequencing of segments. Many of the acoustic observations confirm and extend earlier auditory-based descriptions, for example, increasing durations of C and V segments accompanying increases in syllabic length (Odell et al., 1991). In their discussion, Kent and Rosenbek (1983) suggested that AOS should perhaps not be considered as either a phonological disorder or one of impaired motor programming but that "It may be necessary to consider both types of impairment as coexisting factors" (p.245).

Instrumental studies in acquired neurogenic disorders have investigated all aspects of the speech signal identified by Kent and Rosenbek (1983) as characteristic features of AOS. These can be divided into the following key areas: timing measurements; qualitative assessment of the acoustic signal; articulatory coordination; and articulatory kinematics. The following section is a review of the main instrumental investigations within each of these areas. Similarities and differences between the studies will be highlighted and form the basis for discussion in this thesis.

2.4.1 Timing measurements

Several durational aspects of the speech signal have been investigated in AOS and aphasic speech. Studies of voice onset time (VOT) have provided a large corpus of data and will be reviewed in Section 2.4.1.1. Other timing measurements have also been made in an attempt to classify AOS and separate the disorder from aphasic syndromes.

Whilst durational changes in apraxia of speech, for example slow speech, have been generally accepted as characteristic of AOS (Kent and Rosenbek, 1983) there has been much disagreement as to whether they are compensatory or a primary characteristic of the disorder. Skenes (1987) was interested in the speech rate of apraxic subjects in comparison to normal control speakers and their ability to make temporal adjustments upon request. In an earlier study, Johns and Darley (1970) asked ten apraxic subjects to read a passage at normal and fast speaking rates during which the number of errors produced were noted. However, since they did not directly measure the duration of the utterance they could not be sure whether the subjects did alter their rate, and if so, to what extent. Therefore, Skenes (1987) measured the duration of phrase, target word, initial vowel, medial consonant, and second vowel of the target word for 9 apraxic and 5 normal speakers for two stress conditions and two rates of speech (normal and fast speaking). Using wide band spectrograms and oscillograms, she found that the absolute segment durations were longer for apraxic than normal speakers. Mean durational differences for each word were then computed for the two speaking rates. Skenes (1987) found that the apraxics showed no statistical difference between the two speaking rates in duration of segments measured. She concluded that the slower rate was probably not just compensatory since the apraxic subjects seemed unable to alter their rate upon request. However, Skenes (1987) ignored productions containing errors, focusing her measurements on the first five correct utterances at both speeds. Since the errors may have been a direct result of trying to increase the rate of speech their inclusion in such a study is important. As Sussman, Marquardt, MacNeilage and Hutchinson (1988) state "examination of error free productions will not contribute to our understanding of the underlying neuro-motor related programming deficits of these patients" (p.378).

Duffy and Gawle (1984) examined vowel duration preceding voiced and voiceless consonants in aphasics with and without AOS. They found that the absolute duration of vowels was shorter than normal speakers and that the experimental group exhibited greater variability than normals but maintained vowel duration distinctions as a cue to stop consonant voicing. Tuller (1984) compared VOT and vowel duration in the same patients in an attempt to assess the degree to which bimodal distribution (non overlapping VOT values for voiced and voiceless cognates) was maintained. She was unable to find any relation between the nature or type of distribution in any one subject. Baum and Blumstein (1987) extended this to include Wernicke's aphasics. They found that both Broca's and Wernicke's aphasics maintained the distinction between voiced and voiceless stops as a function of vowel duration. They suggested that aphasic types other than Broca's may also have subtle phonetic impairments.

Seddoh, Robin, Sim, Hageman, Moon and Folkins (1996) looked specifically at speech timing in AOS and conduction aphasia and compared this to normal control speakers. Their aim was to discover whether these two groups of disordered speakers demonstrated the same or different errors of temporal control and relate these to underlying deficits. They were particularly interested in the variability of productions compared to control groups. They felt that an increase in variability would reflect an "instability in the motor speech control system" (p.591). Abnormal variability has previously been identified as a characteristic of AOS (Kent and Rosenbek, 1983; McNeil, Caligiuri, and Rosenbek, 1989; Odell et al.,1990). They hypothesized that if the conduction aphasics demonstrated a similar increase in variability this would indicate that these two disorders had similar underlying motoric deficits. This would oppose the traditional view that AOS was due to a motoric deficit and conduction aphasia a result of a higher level linguistic impairment, an opinion which has recently been challenged (Kent and McNeil, 1987; McNeil and Adams, 1991; McNeil, Liss, Tseng and Kent, 1990). The temporal measures used were stop gap duration (SGD), VOT, second formant transition duration for a vowel (F2D), steady state vowel duration (VD), and consonant-vowel duration (CVD). Variability was measured using scores of standard deviations (SD), both group and individual. Abnormal temporal control was identified in the speech of both AOS and conduction aphasics. Despite this finding, the conduction aphasics did not demonstrate increased variation when compared to the control groups. Seddoh et al. (1996) argued that "If the underlying source of the deficit is the same for both groups, then it would be difficult to account for why they do not exhibit approximately similar patterns of output in their performance" (p.599). They concluded that AOS is a motor speech disorder and the timing deficits in conduction aphasia are likely to be linguistically based. This is quite distinct from Kent and McNeil (1987) who state "conduction aphasia is similar to apraxia of speech" (p.213). However, the value of using standard deviation as a measure of variability is questioned since Seddoh et al. (1996) did not control for rate of speech. The coefficient of variance would have given a more accurate assessment of variability.

A few studies have considered duration of frication noise as a cue to voiced and voiceless fricatives (Code & Ball, 1982; Kent & Rosenbek, 1983; Harmes, Daniloff, Hoffman, Lewis, Kramer & Absher, 1984; Baum & Blumstein, 1987). There seems to have been a general agreement that Broca's, Wernicke's and apraxic speakers all demonstrate durations similar to normal speakers. Blumstein and Baum (1987) conclude that whilst Broca's aphasics and patients with AOS appeared to have difficulties in temporal control and coordination, it could not be said that these patients have an inability to control duration per se since vowel duration could be used as a phonetic parameter to separate voiced from voiceless. Instead, they believe that these patients had difficulty with the timing relation between two independent articulators.

2.4.1.1 VOT

Studies of Voice Onset Time (VOT) have frequently been reported in the literature on apraxic and aphasic speech. Traditionally it has been thought that fluent aphasics, similar to normal speakers, make clear distinctions between voiced and voiceless stops as a function of VOT. Blumstein and Baum (1987) suggest that in English VOT values for voiceless consonants are characteristically longer than voiced (40 to 100+ msecs and 10 to 20 msecs or pre-voiced respectively). There is a general agreement that Broca's aphasics and apraxics tend not to make a clear distinction between voiced and voiceless consonants (Freeman, Sands and Harris, 1978; Ziegler and von Cramon, 1986a; Blumstein, Cooper, Zurif and Caramazza, 1977; Blumstein, Cooper, Goodglass, Statlender and Gottlieb, 1980). Instead they produce VOT values which often fall between the normal range for a particular pair of stop cognates. This has often been cited as evidence to suggest that these subjects demonstrate a disturbance in the timing and coordination of laryngeal and supralaryngeal articulatory events.

Freeman et al. (1978) hypothesized that voicing errors occurring in their apraxic subject were a result of a defective temporal coordination. They found that the apraxic subject did not demonstrate voicing lead for voiced stops and that lag times for these were longer than control subjects. This, coupled with the finding that voiceless stops had shorter lag times, resulted in an overlap of the two categories voiced/voiceless.

Ziegler and von Cramon (1986b) were also interested in the timing deficits in apraxic subjects. They investigated 8 patients diagnosed as apraxic and compared them to 12 normal speakers. They conducted three experiments looking at the phasing of different articulators. In their study of VOT they noted a number of differences between apraxic and normal speakers. The apraxics demonstrated increased variability in VOT measures which resulted in an overlap in the values of voiced and voiceless cognates. They suggest that in a broad phonetic transcription of the type used in a perceptual investigation the voiced consonants would have been transcribed as their voiceless counterparts as a result of the increased values in VOT for the voiced consonants. They argue that perhaps these are not substitutions but that the values can be "considered to mark the extreme points in a continuum of voicing lags" (p.46). Therefore the perceived phonemic errors (substitutions) are in reality phonetic errors.

Blumstein et al. (1977) and Blumstein et al. (1980) believed that there were differential patterns of performance in the production of VOTs as a function of aphasia type. Additionally, they found that the VOTs for their group of conduction aphasics could be separated into two which they explained by suggesting that there are two distinct underlying anatomical patterns in conduction aphasia. These differences were not found by Shewan, Leeper and Booth (1984) investigating VOTs in aphasic and normal speakers. Their study extended earlier investigations by considering additional factors such as the age of the subject and place of articulation. Nine Broca's and six conduction aphasics made up the experimental group and their VOTs were compared to nine normal control subjects. The data from the control subjects was compared to an earlier investigation by Lisker and Abramson (1964) who measured the VOT values of four normal young speakers. Shewan et al. (1984) found that their older normal subjects showed extended VOT boundaries, higher means for voiceless phonemes and a large number of productions fell outside the ranges suggested by Lisker and Abramson (1964). In addition, Shewan et al. (1984) found VOTs sensitive to both place and voicing which supported the work of Blumstein et al. (1980). Shewan et al. were also interested in the type of error made, a phonetic gap error, (where the VOT value falls within the area of separation between voiced and voiceless cognates), or a phonemic error. The latter they divided into Phonemic A errors (a voiced target with a VOT value above the lower boundary of its voiceless cognate) and Phonemic B errors (the VOT value for a voiceless target fell within the boundaries of its voiced partner). A significant interaction between these error types and place of articulation was noticed with more phonetic gap errors occurring for /t-d/ than /p-b/ or /k-g/ and Phonemic B errors for /k-g/ than for /p-b/ and /t-d/. They also found more errors for the voiceless triad /p, t, k/ than for the voiced. Three significant findings emerged from the study: VOT values are sensitive to age; Broca's and conduction aphasics show similarities in their phonological-articulatory problems; and Broca's and conduction aphasics both produce phonetic and phonemic error types. From this Shewan et al. (1984) concluded that "dichotomous explanations of motor speech programming problems and phonetic selection problems ...... are too simplistic" (p.217).

Ryalls, Provost and Arsenault (1995) have also recently challenged the phonetic/phonemic division of aphasic patients with respect to VOT measures. They investigated 10 French speaking aphasics (5 Broca's and 5 Wernicke's) and 5 French speaking normal subjects matched for age. They found, similar to the normative data, that both Broca's and Wernicke's aphasics demonstrated two distinct VOT categories. However, the average distance between voiced and voiceless pairs (/b-p/, /d-t/, /g-k/) was less for the aphasic speakers (180 msecs for Broca's, 169 msecs for Wernicke's) compared to normal speakers (199 msecs). This contradicts earlier studies since they found that it was the Wernicke's and not the Broca's aphasics that demonstrated the least amount of VOT difference between the voiced and voiceless cognates. They also found through calculations of standard deviation that the Wernicke's aphasics were more variable in their productions than the Broca's aphasics.

Ryalls et al. (1995) were also interested in the errors produced by the two groups of aphasics. They found that of the total number of errors produced by Broca's aphasics (9%) an average of 4% were phonetic and 5% were phonemic. For Wernicke's aphasics there was an equal number of phonetic compared to phonemic errors (4% of each). Earlier investigations (for example Blumstein, 1980) have suggested that Broca's aphasics make more phonetic errors than Wernicke's. These disagreements may be a result of language differences. Ryalls et al. (1995) note that the voiced stops in French typically demonstrate negative VOT values but in English they are positive. Therefore they say that a greater average VOT difference between voiced and voiceless stops for English would be expected in French compared to English. They conclude that a "smaller VOT difference between voiced and voiceless stops for English could perhaps exacerbate the problem Broca's aphasics have in maintaining fine distinctions and hence result in more phonetic errors" (p.212).

2.4.2 Acoustic qualitative studies

Some studies have taken a more qualitative approach as opposed to a quantitative approach when investigating acquired neurogenic speech disorders. These studies have the added advantage of detecting intra-subject and inter-subject variability which is frequently overlooked in quantitative investigations. Weismer and Liss (1991) note the importance of these types of investigation especially when one considers that variability is "the rule rather than the exception" (p.246) in acquired neurogenic speech disorders.

Shinn and Blumstein (1983) looked at the spectral characteristics of 5 aphasic patients (4 Broca's and 1 Wernicke's from Blumstein et al., 1980) and compared these to 6 normal speakers (taken from Blumstein and Stevens, 1979). Whilst analysis of the spectral properties from the speech of Broca's aphasics in the earlier investigation suggested an inability to maintain the voiced/voiceless distinction, Shinn and Blumstein (1983) found that the spectral properties of the consonants were similar to the normals. This was particularly true of consonants perceived as correct. However, the data from the aphasics was not entirely normal since they found much less high frequency energy for alveolar stop consonants in the aphasic speech than for normals. Therefore spectral analysis revealed abnormalities in the speech of the aphasics which was not detected using quantitative investigative procedures (VOT).

Ziegler and Hoole (1989), in a combined acoustic and perceptual study, investigated the tense-lax opposition in aphasic vowel production of four German speakers (1 Broca's, 1 conduction, 1 Wernicke's and 1 normal speaker). Acoustic measurements included a waveform editing program to measure the length of the stressed vowels in "bitten" and "bieten", and a LPC-based program to calculate formant trajectories. F1 and F2 values for the mid-point of each vowel were determined from the trajectories. The data from the normal speaker indicated a clear separation of the two vowel categories with a distinct trade-off between vowel duration and vowel quality. Therefore vowels similar in their duration differed widely in their formants and similar formant values demonstrated dissimilar vowel durations. These patterns were not replicated in the speech of the aphasic subjects. Whilst the Broca's aphasic produced vowels with average durations and demonstrated formant values similar to the normal speaker there was a clear overlap in the vowel quality dimension and no trade-off between duration and quality. Tense and lax vowels produced by the Wernicke's aphasic overlapped in both temporal and spectral domains with some vowels assuming values characteristic of the opposite cognate. Ziegler and Hoole (1989) concluded that the acoustic data suggested "gradual and non-categorical deviations in either timing or articulatory configuration, or both" (p.461) for the aphasic subjects. These results do not accommodate an explanation based on incorrect phoneme selection where categorical change would be predicted. Instead, it seems to support the view that aphasics with anterior and posterior lesions both demonstrate subtle phonetic distortions.

Weismer and Liss (1991) conducted an acoustic and perceptual experiment to investigate speech production deficits in motor speech disorders which they felt was a more direct comparison of the acoustic analysis with the perceptual data than their previous investigations (Liss and Weismer, 1989). They believed that previous studies which claimed to compare acoustic analysis with the perceptual data were not really doing this. They suggested that the quantification methods chosen were inappropriate since they did not take account of the intra- and inter-subject variability in normal and disordered speech. They emphasised that such methods were only useful for error free productions which consequently eliminated much of the data from the disordered speech samples. Weismer and Liss (1991) state that their study "presents an approach that .... has more theoretical power than the classical parametric analysis" (p.246). The qualitative approach they favour is similar to that of Kent and Rosenbek (1983) except Weismer and Liss (1991) use contrastively stressed utterances and a qualitative analysis of repetitions. Weismer and Liss (1991) were particularly interested in formant trajectories since these they consider "provide a straightforward qualitative index of the magnitude and speed of change in vocal tract geometry" (p.247). They found much within subject variation for apraxic subjects. Formant trajectories were variable, there were variations in the duration of the vocalic nucleus, and the temporal structure of their utterances contained relatively large consonantal intervals when compared to normals which were predominated by vocalic segments. Four major properties of apraxic speech were identified: exaggerated articulatory gestures and misdirected formant trajectories; articulatory perseveration; groping behaviours that were fragmented; and consistency across repetitions of many of these phenomena.

In 1992 Liss and Weismer reiterated their view of the importance of qualitative analysis by stating "qualitative examination can expose phenomena that must be explained in theoretical accounts, and in fact takes advantage of intra- and inter-subject variability as objects of theoretical interest, as opposed to a view wherein variability is an obstacle to successful treatment of the data" (p.2985). They further analysed the data from the combined acoustic and perceptual study (Weismer and Liss, 1991). From this they suggested that the formant slope and segment duration can themselves under represent important differences between and within subjects. Instead they suggest that the portion prior to the slope may contain vital information. Stringent quantification procedures would overlook this area but a qualitative analysis would reveal important differences. Through their analysis they found that the apraxic subjects produced plateaus directly prior to the most rapidly changing portions of the trajectories which were not seen when examining normal data. This they felt to be consistent with what they termed "articulatory immobility" (p.2986). Ziegler and Hoole (1989) have also suggested the importance of the dynamic aspects of vowel onset and offset. They believed that vowel duration and target formant frequencies were not sufficient to explain listeners' decisions in their perceptual study since they were often able to identify considerably aberrant vowels in what they termed the F2-F1 overlap region.

Wambaugh, Doyle, West, and Kalinyak (1995) investigated the production of /ʃ/ by two adults diagnosed as Broca's aphasics with AOS. Since the phoneme /ʃ/ is often perceived as an [s] in these subjects, they were interested in whether the substituted sound differed acoustically from the correctly produced homonyms. Of interest to them was the frequency of the spectral energy peak (FSPE) since it was felt that this was probably an important perceptual cue. The incorrect productions for one subject (S1) in word final (WF) position and another, S2, in word initial (WI) position were compared to their correct productions of /ʃ/ and /s/. For S1, the incorrect productions were acoustically different from his homophonous [s] productions. From this they concluded that the errors produced by this subject could not be straightforward substitutions but more probably errors of distortion. Conversely, the FSPE for productions of /ʃ/ perceived as [s] in WI position for S2 were the same as the correct [s] productions and therefore suggestive of a substitution. However, Wambaugh et al. (1995) also noted that S2 demonstrated a wide variability in the FSPE of his incorrect /ʃ/

productions compared to the correct [s] productions. They state "we cannot rule out problems in precision of production as a source of his errors" (p.188).

2.4.3 Articulatory coordination

Several studies investigating the speech of patients with acquired neurogenic disorders have been interested in articulatory transitions and the ability to coarticulate the organs of speech. Coarticulation has been defined as "the movements of different articulators for the production of successive phonetic segments (which) overlap in time and interact with one another" (Farnetani, 1997: p.371). Apraxic speech errors have frequently been linked to problems in coarticulation. This has supported the view that AOS is a result of a motoric deficit since the speaker is unable to control the timing of different articulators.

Errors investigating articulatory coordination, other than studies of VOT, have been restricted to subjects with anterior lesions diagnosed as either apraxic or Broca's aphasics. It has been assumed that aphasics with posterior lesions do not present with motoric deficits and therefore their coarticulatory abilities have not been investigated. Perceptual, acoustic and physiological methods have resulted in conflicting findings.

In a study of anticipatory coarticulation, Zieger and von Cramon (1985) used gated speech stimuli to assess the articulatory anticipation of vowel gestures in an apraxic, a dysarthric and three normal speakers. They found that the vowels produced by the apraxic speaker were identified later than for normal speakers by nine trained phonetic students. This delay was considered to indicate a disturbance in the phasing of motor speech events and therefore in keeping with the view that AOS is a motoric problem. However, they acknowledged the limitations of their auditory-based analysis by stating that it was a "suitable starting point for an acoustic approach" (p.129). Such an approach was taken when they investigated the lingual/velar phasing and lingual/labial phasing (the timing of velar and labial movements in relation to lingual gestures) (Ziegler and von Cramon, 1986b). Lingual/velar phasing was assessed by measuring the sound pressure level (SPL) during tri-syllabic nonsense words and real words containing alveolar and velar nasals. They found SPL changes of up to -6dB in apraxic speakers compared to normals where the maximum SPL reductions recorded were 1dB. The results were taken to indicate a premature elevation of the velum causing a decrease in sound pressure for apraxic speakers. Their final experiment concerning lingual/labial phasing assessed the degree to which lip rounding gestures were anticipated, an extension of their earlier perceptual study. The results of the acoustic study supported the earlier findings with anticipatory lip rounding often failing to occur at all. They concluded that "patients with apraxia of speech have a basic problem in phasing individual speech gestures appropriately" (p.48) and went on to say that this was "evidence that inter-articulatory phasing could be responsible for a number of so-called phonemic errors". Their results challenged the phonemic/phonetic dichotomy by suggesting that it was not only phonetically distorted sounds that may indicate a motoric deficit but also errors previously considered phonological in nature.

Katz (1988) was unable to support the findings of Ziegler and von Cramon (1985, 1986b). In his acoustic and perceptual study of anticipatory coarticulation in aphasia he found no overall deficit or delay in the coarticulation of anterior aphasics. He conducted two experiments, one employed linear predictive coding (LPC) to assess the bilabial and lingual coarticulation and a second was a purely perceptual experiment. He found that listeners were able to identify the vowel productions of all subjects at a level above chance and there was only a small statistically significant group difference observed for productions of [sV], [skV] and [tV], anterior aphasics demonstrating significantly lower scores. It has been suggested that the results may have arisen as a result of differences in the subjects that were investigated since Ziegler and von Cramon

(1985) used German speakers diagnosed with AOS whilst Katz (1988) used English subjects diagnosed using the Boston Diagnostic Aphasia Examination (BDAE). It should also be noted that only 3 out of the 5 anterior aphasics in Katz's study were able to produce all of the data. Two anterior aphasics were unable to articulate CCV sequences. Therefore many of his results are based on a small subset of anterior aphasics which are not necessarily representative of this whole population.

Sussman et al. (1988) used articulatory and electromyographic records to assess anticipatory lip rounding and jaw lowering in 6 Broca's aphasics. Whilst their data supported the view of Katz (1988), that aphasics demonstrate anticipatory coarticulation, they feel this cannot be generalized since they also found many idiosyncratic forms. Instead they stress the importance of examining each patient individually with the inclusion of error free productions.

Itoh and Sasanuma (1984) also reported on the temporal organisation of different articulators of an apraxic speaker using X-ray microbeam. Pellets were attached to the lower lip, lower incisor, tongue tip and dorsum and the nasal surface of the velum. On comparison with a normal speaker, they found that the apraxic subject showed disorganization of timing among several of the articulators. In particular, the timing relationship between velar lowering and movements of the tongue and lip for /n/ were variable. The corresponding productions from the normal speaker were consistent. They concluded from their investigation that inconsistent articulatory errors were due to difficulties with motor programming.

2.4.4 Articulatory kinematics

Itoh and Sasanuma (1984) report on the articulatory movements of aphasic (including apraxic) speakers using fibreoptic and X-ray microbeam techniques. Using the former, they recorded the velar movements of one apraxic, two aphasic and one normal speaker. The apraxic subject produced unique articulatory movement patterns characterized by the following: less regular oscillatory movements; variability over repetitions; and phonetic changes from /n/ to [d]. They argue that these are phonetic errors rather than due to a selection or retrieval error because the velum was not in as high a position as would be expected during normal production of /d/. Of the aphasic subjects, one produced three out of five articulations consistently. The other aphasic was more variable in his productions but no phonetic changes resulted.

In 1987 Itoh and Sasanuma looked at the articulatory velocities and displacements for labial and mandibular articulatory movements in 5 Broca's and 3 Wernicke's aphasics using infra red light-emitting diodes (LEDs). These they compared to 10 subjects with normal speech and hearing. The normal group's peak velocities for lip and jaw movement showed a strong positive correlation with the magnitude of the displacement suggesting a constant duration for any given phoneme. The Wernicke's patients showed no signs of deviation from the normal patterns. However, Broca's aphasics were characteristically inconsistent in both velocity and displacement with no observable correlation between the two. Itoh and Sasanuma (1987) state that "Broca's aphasic patients as a group definitely have difficulty in controlling their articulatory velocity" (p.159).

2.4.5 Variability

A consistent feature of AOS which has been identified through instrumental studies is the increased variability in all aspects of the speech signal compared to data from normal speakers. For example, an increase in variability for a variety of different durational measures has been noted by Duffy and Gawle (1984), McNeil et al. (1989), Odell et al. (1990) and Seddoh et al. (1996). Studies of VOT have also concluded that apraxic speakers demonstrate increased variability (Ziegler and von Cramon, 1986a, 1986b) as have kinematic investigation (Itoh and Sasanuma, 1984, 1987). A more thorough examination of this variability has been provided by qualitative studies which have looked in detail at intra- and inter-subject differences, for example Kent and Rosenbek (1983), Weismer and Liss (1991), Liss and Weismer, (1992) and Wambaugh et al. (1995).

This increase in variability has been taken as evidence that AOS is a result of a motoric deficit. Furthermore, it has been used to separate AOS from conduction aphasics (Seddoh et al., 1996) who, despite evidencing durational changes in both groups of speakers only identified an increase in variability for those diagnosed with AOS.

Whilst variability has been identified and proposed as a defining characteristic of AOS from the results of these studies, the validity of the conclusions from some of the investigations must be questioned on methodological grounds. The experimental group has sometimes been compared to a single control speaker (Itoh and Sasanuma, 1984) or a group of normal speakers not matched for size (Skenes, 1987; Ziegler and Hoole, 1989). It would appear that normal variability is a poorly defined and researched area yet it is a characteristic frequently mentioned in the literature on AOS.

2.4.6 Non-speech oral movements

The study of non-speech oral movements in apraxic speakers has attempted to add to our knowledge of neurological disorders. The theory behind investigating these movements lies in the notion that if AOS is a linguistic disorder then non-speech oral movements should be unaffected. Conversely, if the deficit is purely motoric in origin then we would expect to see abnormalities of motor control affecting speech and non-speech movements. McNeil, Weismer, Adams and Mulligan (1990b) assessed the isometric force and static position control of upper lip, lower lip, tongue jaw and finger at two force displacement levels. They investigated 5 normals, 4 apraxic subjects without concomitant dysarthria or aphasia, 4 conduction aphasics and 4 ataxic dysarthric speakers. The variable force was chosen since McNeil et al. (1990) state it is "believed to be among the critical parameters in the control of speech and limb movements" (p.255). The subjects were required to match one channel under their control to a second channel displayed on a scope. This was achieved by either displacing (static position) or compressing (isometric force) a cursor with one of the orofacial structures or finger. Response speed was not considered important and therefore not measured. The apraxic subjects produced greater instability during the isometric force experiments than normal or aphasic speakers. This did not appear to be linked to a particular structure or force level. This instability was also noted during assessment of static position control. McNeil et al. (1990b) also noted much inter-subject variability which they felt may be related to site of lesion, location, time post onset or severity of performance deficit. Furthermore, the patterns of deficit were not necessarily consistent across structures such that the performance on one type of force task was not predictive of performance on another.

2.4.7 Summary of findings from instrumental studies

The following is a summary of the main findings from instrumental studies which are relevant to this thesis. These points will be discussed in relation to the results of this investigation. A summary of the instrumental studies reviewed in this section are summarized in Table 2-2.

1. Not all durational measures in the speech of apraxic and aphasic speakers are impaired, for example, the duration of frication noise as a cue to voiced and voiceless fricatives is maintained in AOS, Broca's and Wernicke's aphasics (Code & Ball, 1982; Kent & Rosenbek, 1983; Harmes et al., 1984; Baum &

Blumstein, 1987a) and Broca's and Wernicke's maintain the distinction between voiced and voiceless stops as a function of vowel duration (Baum and Blumstein, 1987a).

2. Durational measures, for example VOT, show almost consistent differences in deficits.

3. AOS is characterized by an increase in variability in timing measurements, VOT, articulatory coordination and articulatory kinematics.

4. It is generally believed that apraxic speakers have particular difficulty in the timing and coordination of articulatory movements (Ziegler and von Cramon, 1985, 1986b; Itoh and Sasanuma, 1984).

5. Qualitative studies are better able to detect intra- and inter subject differences and idiosyncrasies.

Author	Date	Study	Main findings
Code & Ball	1982	Duration of frication in AOS & aphasia as a cue to voiced/voiceless fricatives	Broca's, Wernicke's & AOS demonstrate durations similar to normals
Kent & Rosenbek	1983	Acoustic correlates of AOS	Slow speaking rates with prolongation of transitions Steady states Intersyllabic pauses Reduced intensity variation Slow & inaccurate movements Incoordination of articulators Initiation difficulties Errors of selection & sequencing of segments
Duffy & Gawle	1984	Vowel duration in aphasics with & without AOS	Absolute duration of vowels shorter in aphasics Aphasics demonstrate increased variability Aphasics maintain vowel duration distinctions as a cue to stop consonant voicing
Tuller	1984	VOT & vowel duration in aphasia	No relation between nature & type of distribution
Harmes et al.	1984	Duration of frication in AOS & aphasia as a cue to voiced/voiceless fricatives	Broca's, Wernicke's & AOS demonstrate durations similar to normals
Skenes	1987	Durational changes in AOS	Absolute segment durations longer in AOS AOS did not differentiate speaking rates
Baum & Blumstein	1987a	VOT & vowel duration in aphasia	Broca's & Wernicke's aphasics maintain voice/voiceless distinction as a function of vowel duration
Blumstein & Baum	1987	Duration of frication in AOS & aphasia as a cue to voiced/voiceless fricatives	Broca's & AOS have difficulties in temporal control & coordination but they maintain ability to separate voiced/voiceless with vowel duration
McNeil et al.	1989	Timing in AOS	Abnormal variability
McNeil et al.	1990	Effects of speech rate on timing in AOS & conduction aphasia	AOS & conduction aphasics showed similarities in timing deficits
McNeil & Adams	1991	Speech kinematics in AOS, conduction aphasia, ataxic dysarthria & normals	AOS & conduction aphasics showed similarities in timing deficits
Seddoh et al.	1996	Measures of SGD, VOT, F2D, VD, CVD in AOS & conduction aphasics	Abnormal temporal control for both groups AOS demonstrated abnormal variation but conduction aphasics did not
Blumstein et al.	1977	VOT in aphasia	Differential patterns as a function of aphasia type
Freeman et al.	1978	VOT in AOS	Overlap in the voiced/voiceless categories
Blumstein et al.	1980	VOT in aphasia	Differential patterns of VOT as a function of aphasia type
Shewan et al.	1984	VOT in aphasia	VOT sensitive to place & voicing VOT boundaries extend with age
Ryalls et al.	1995	VOT in French speaking Broca's & Wernicke's aphasics	Two distinct VOT categories for both groups Wernicke's demonstrated least amount of VOT difference between voiced & voiceless Wernicke's productions were most variable

Authors	Date	Study	Main findings
Shinn & Blumstein	1983	Spectral characteristics of Broca's, Wernicke's & normal speakers	Broca's similar to normals Aphasics demonstrate less high frequency energy for alveolar stops
Ziegler & Hoole	1989	Tense-lax vowel opposition in aphasics	Normal speakers show clear separation with a trade-off between vowel quality & vowel duration Broca's produced clear overlap & no trade-off Wernicke's produced overlap
Weismer & Liss	1991	Qualitative analysis of formant trajectories in AOS	Exaggerated articulatory gestures & formant trajectories Articulatory perseveration Groping behaviours Consistency across repetitions
Liss & Weismer	1992	Re-examination of Weismer and Liss 1991 data	Formant slope & segment duration can under represent differences Portion prior to the slope may be important
Wambaugh et al.	1995	Incorrect productions of /ʃ/ in Broca's aphasia with AOS	One subject's errors were best classified as distortions the other subject's errors could be classified as substitution or distortion
Ziegler & von Cramon	1985	Anticipatory coarticulation of vowel gestures in AOS and dysarthria	Vowels produced by AOS were identified later than for normals
Ziegler & von Cramon	1986	Articulatory coordination in AOS	AOS characterized by difficulties in phasing different articulators
Katz	1988	Anticipatory coarticulation in anterior aphasics	No overall deficit or delay in anticipatory coarticulation
Sussman et al.	1988	Anticipatory lip rounding using articulatory & electromyographic records in Broca's aphasics	Aphasics demonstrated anticipatory lip rounding
Itoh & Sasanuma	1984	Fibreoptic & X-ray microbeam of AOS, aphasic & normal	AOS produced unique articulatory movements, disorganization
Itoh & Sasanuma	1987	Infra red LEDs in Broca's & Wernicke's aphasics	Broca's inconsistent lip and jaw velocities with no correlation

Table 2-2: Summary of the main instrumental studies and their findings.

2.5 EPG Studies Of Acquired Neurogenic Speech Disorders

Whilst EPG has been used with a range of client groups, research into neurogenic speech disorders has been limited to a few case studies. More recently it has been used in the treatment of one patient with acquired AOS (Howard and Varley, 1995). To date the research of neurologically impaired speakers has involved patients considered to have motoric disabilities, both dyspraxia and dysarthria. Acquired neurogenic speech disorders with a presumed linguistic origin have not been investigated. Most of the studies have focused on identifying the characteristics of the disordered speech with the results being comparable.

The earliest known published study was by Washino, Kasai, Uchida and Takeda (1981) who presented an individual case report of a patient with pure AOS comparing data from this subject to a single control speaker. They focused on the patient's ability to articulate the syllable /ta/ in word initial, medial and final positions and in the nonsense sequence /pataka/. Washino et al. (1981) identified both spatial and temporal abnormalities in the neurogenically disordered speech. Lingual/palatal contacts were typically made over a longer duration and there was a greater area of contact. This pattern has also been identified in the speech of stutterers (Wood, 1995), a disorder which is often viewed as a motor problem. Whilst the basic pattern for an alveolar plosive appeared to be maintained the contact patterns were more variable than the control speaker. From this Washino et al. (1981) concluded "the fact that there is no real consistency in the errors since the ability to pronounce [ta] ... remains relatively intact in all positions, ... is evidence enough to prove that pure apraxia of speech is not caused by disorders at the level where sound images are extracted for proper utterances, nor by paralysis" (p.145). They went on to say "in spite of inconsistency in his articulation, since F.Y. maintains the basic pattern of articulation, he is capable of extracting the right sounds for articulation" (p.149) and the characteristics of the speech patterns noted were evidence of "disorders at the level of motor programming" (p.149). They also noted "searching behavior", an unnecessary movement of the tongue without phonation whose lingual/palatal contacts appeared similar to a preceding alveolar plosive which had substituted a target velar. Whether this is what Darley et al. (1975) termed a groping behaviour or the same as the misdirected articulatory gestures that were identified by Hardcastle and Edwards (1992) and Sugishita, Konno, Kabe, Yunoki, Togashi, and Kawamura (1987) (see below) is unclear. Darley et al. (1975) state that apraxic patients "visibly and audiby grope as they struggle to produce correct articulatory postures in forming words" and that the "articulation is frequently off target" (p.250). Since the gesture that Washino et al. (1981) describe is a discrete, single movement of the tongue which was undetected through auditory analysis it does not seem to fit Darley et al's. (1975) description of a groping behaviour. It is felt that Darley et al's. (1975) definition implies a more gross and laboured movement or series of movements and not an isolated gesture which is readily identifiable as a lingual gesture.

Washino et al. (1981) offered two explanations for this "searching behavior". The first concerns the subject identifying the error through auditory perceptual analysis. Following this, attempts to produce the correct articulation by the apraxic speaker resulted in the same error, this time unphonated because the speaker identified the mistake. The second explanation concerned the subject repeating the gesture to "double check" that an error had in fact been made. In concluding they say the presence of these "searching behaviors" "supports the theoretical construct that there exists motor programming prior to phonetic realization" (p.158).

Hardcastle, Morgan Barry and Clark (1985) investigated articulatory and voicing characteristics of two adult dysarthric and one adult dyspraxic speaker. They identified characteristics which not only distinguished the two conditions as separate neurogenic disorders but also found similarities between them. Whilst the dysarthric errors were mostly distortions of the target configuration, the dyspraxic speech was characterized primarily by errors of sequencing and selection. However, both demonstrated spatial and temporal variability in their attempts at the targets but these were more prominent in the speech of the dyspraxic.

In his detailed study of a patient with verbal dyspraxia, Hardcastle (1987) identified many of the findings of the earlier study but also further characteristics of the disorder. Some of the difficulties experienced concerning temporal integration were likened to the speech of stutterers. Both repetitions and prolongations of lingual consonants were noted, although unlike pathological stuttering, repetitions usually consisted of a single repetition of the target sound. Unsurprisingly, most errors usually occurred in word initial position and during production of consonant clusters, a characteristic noted earlier by Darley et al. (1975) through auditory perceptual judgments. This is considered to reflect the relatively more complex encoding required for the production of phonemes in these positions. Furthermore, Hardcastle (1987) noted many errors were undetected by auditory analysis alone and were only identified through detailed analysis of the electropalatograms.

These unidentified errors featured strongly in the following studies. Sugishita et al. (1987) looked specifically at what appeared auditorily to be errors of omission in one left-handed and one right-handed apraxic speaker. They discovered three types of omission errors in word initial position: those which were considered true omissions with no corresponding lingual/palatal contact; omissions where incorrect contacts were noted from the EPG data; and so-called omissions where correct contact for the target sound was noted. In addition to these findings they found that the patients tended to substitute either a [t] or [tʃ] for other sounds. This, they suggested, was evidence of an inability to inhibit tongue activity. These movements are felt to be similar to the "searching behaviors" noted by Washino et al. (1981).

Edwards and Miller (1989) in their electropalatographic investigation of speech errors and motor agility in a dyspraxic adult emphasized that many errors revealed through analysis of the EPG data were not available to the listener. Their subject was diagnosed, through auditory-based analyses, as having dyspraxic with accompanying phonemic paraphasic errors. Examination of the EPG data suggested that the phonemic paraphasias were not always as they appeared auditorily. For example, production of the word "tier" in isolation was heard and transcribed by two judges as [kɪər]. But closer inspection of the EPG data indicated contact in the central alveolar region, some narrowing in the velar region during the closure phase and an asymmetrical lateral release. Therefore, the EPG data had provided information unavailable to the listeners who had transcribed a straight substitution of [k] for /t/ suggesting a phonemic paraphasia. Without this additional information we are led to believe that this error is most probably at the level of phoneme selection. However, the EPG data indicates that there may also be a motoric impairment. In their conclusions Edwards and Miller (1989) suggest that there is a "common relationship between so-called speech dyspraxia and phonemic paraphasic errors" (p.123).

Edwards and Miller (1989) also noted that the errors produced by their dyspraxic patient were not confined to either one place or manner of production. In addition the placing and release of the tongue contacts were problematic. During a repetition task they noted that the contacts made during a closure phase were not maintained correctly.

The articulatory errors produced by apraxic subjects were summarized by Hardcastle and Edwards (1992). In their paper entitled "EPG-based description of apraxic speech errors" they compare the pathological speech errors to seven normal quasi-static spatial configurations for lingual obstruents and the lateral approximant /l/

which they identify. The articulatory difficulties of four apraxic speakers are described in terms of six errors: misdirected articulatory gestures; distorted spatial patterns; omission of target gestures; seriation problems; repetition of patterns; and abnormal temporal spatial variability (for a detailed description of the quasi-static patterns and the apraxic error patterns see Hardcastle and Edwards, 1992). Of particular interest in this thesis are the misdirected articulatory gestures, difficulties in transitional timing and the atypical variability that was identified. The misdirected articulatory gestures always involved velar contacts and were readily identified as one of the quasi-static patterns associated with normal speech. They were often undetected through auditory analysis and are felt to be similar to the alveolar gestures noted by Washino et al. (1981) and Sugishita et al. (1987). Increased variability has already been noted in the temporal, kinematic and qualitative studies of AOS reviewed earlier. All subjects in Hardcastle and Edwards (1992) study produced an abnormal amount of spatial variability, and three out of the four apraxic speakers were considered temporally more variable. Deficits in transitional timing are discussed in more detail below.

2.5.1 Coarticulation of consonant sequences in an apraxic speaker

Ingram and Hardcastle (1990) looked specifically at the coarticulatory abilities of a single apraxic and two control speakers. The investigation involved the perceptual investigation of coarticulatory effects in conjunction with EPG and spectrographic analysis of the speech signal. There were two main aims: to assess the magnitude and direction of coarticulation in the apraxic speaker; to investigate the relationship between perceptual and instrumental analysis of coarticulatory effects. The corpus consisted of six words sampling velar/alveolar sequences word medially which were taken from another investigation. These items were chosen specifically for two reasons: auditory/perceptual anomalies were noted which were not obviously reflected in the corresponding EPG data; certain anomalies in the EPG patterns which did not appear to have any impact perceptually. Individual items were digitally spliced between the two consonants and listeners were asked to make judgments concerning these two sounds, specifically how alveolar or velar they sounded. From the perceptual analysis Ingram and Hardcastle (1990) noted less consistency in the perceptual responses made of apraxic speech compared to the controls and anticipatory coarticulation was not so strongly perceived in the apraxic speech. The EPG analysis suggested that the apraxic speaker avoided temporal overlap and showed abnormally long latencies between the two consonant gestures. In addition, Ingram and Hardcastle (1990) noted abnormal EPG patterns (e.g. double alveolar/velar articulations during the WI /t/ in "tickling") which were not identified through perceptual auditory analysis. They suggested that these gestures were not identified because they had no acoustic consequences. These are presumably similar to the misdirected gestures noted by Washino et al. (1981), Sugishita et al. (1987) and Hardcastle and Edwards (1992).

A lack of temporal overlap was also identified by Edwards and Miller (1989) and Hardcastle and Edwards (1992). The former study involved a single speaker whose lingual/palatal contact patterns were also analysed by Hardcastle and Edwards (1992). Seriation problems were noted for all four apraxic speakers. This frequently took the form of abnormally long latencies between the alveolar and velar or velar and alveolar sequences, for example the word initial /kl/ sequence in "clock" or the word medial /tk/ sequence in "kitkat". One subject demonstrated difficulty in alveolar/velar sequences but did not demonstrate abnormally long latencies during the production of velar/alveolar sequences. In addition to transitional timing deficits, Hardcastle and Edwards (1992) also noted errors in the sequencing of the target phonemes which often resulted in reversal in the ordering of the two gestures.

2.5.2 Summary of findings from EPG studies into acquired neurogenic speech disorders

Whilst EPG studies into acquired neurogenic speech disorders have been limited many of the findings have been replicated which is not true of all instrumental studies outlined in this review. The following is a summary of the abnormalities that have been detected through analysis of EPG data in the speech of adults with acquired neurogenic speech disorders which are especially relevant to this thesis:

1. An increase in the duration of lingual/palatal contacts (Washino et al., 1981; Hardcastle, 1987).
2. An increase in the area of lingual/palatal contacts (Washino et al., 1981).
3. Increased variability of target gestures (Washino et al., 1981; Hardcastle and Edwards, 1992).
4. The identification of misdirected articulatory gestures ("searching behaviors") which were not perceived through auditory analysis (Washino et al., 1981; Sugishita et al., 1987; Edwards and Miller, 1989; Hardcastle and Edwards, 1992).
5. Apraxia of speech is characterized primarily by errors in sequencing and selection (Washino et al., 1981; Hardcastle et al., 1985).
6. Identification of some lingual/palatal contacts have only been possible through analysis of the EPG data and not through auditory perceptual analysis, for example many of the misdirected articulatory gestures (Washino et al., 1981; Hardcastle, 1987; Sugishita et al., 1987; Edwards and Miller, 1989; Hardcastle and Edwards, 1992).
7. Errors are not restricted to a single manner or place of production (Hardcastle et al., 1985; Hardcastle, 1987; Edwards and Miller, 1989; Hardcastle and Edwards, 1992).

2.6 Models Of Speech Production

The study of speech disorders is imperative for the development of comprehensive models of speech production. For a model to be acceptable it must be able to handle pathological speech in addition to normal speech data. A number of different theoretical models have been developed in an attempt to account for the speech errors in neurogenic disorders. The focus of each model is different, for example some major directions have included neural, articulatory, vocal tract, functional and motor control models. A neural model of speech production for example, details the nervous system processes that control speaking whereas an articulatory model is primarily concerned with movements of the individual speech structures. Since different models are intended for different purposes comparison of individual models is difficult. Therefore this section proposes to describe two models of speech production, a neural model and a functional model, which seem particularly relevant for the nature of the disabilities described in this dissertation since they can assist in explaining certain speech characteristics. Speech data collected in this investigation will be related to these models.

2.6.1 A neural model of speech production

Kent (1990) proposed a neural model which he felt could be related to many acquired neurological disorders. This model was developed from an earlier model of movement control (Allen and Tsukahara, 1974) following changing conceptions of neural control. Allen and Tsukahara's model depicted the pathways for planning, programming and execution for voluntary movement (see Figure 2-2). The pathways and structures involved are not specific to speech. In this early model the planning of action was thought to involve the parietal, frontal and temporal cortices. A system composed of the premotor cortex, supplementary motor area, thalamus, lateral cerebellum and the motor cortex was proposed for the programming of movement. It was believed that the medial cerebellum monitored motor instructions from the motor cortex and revised them when required.

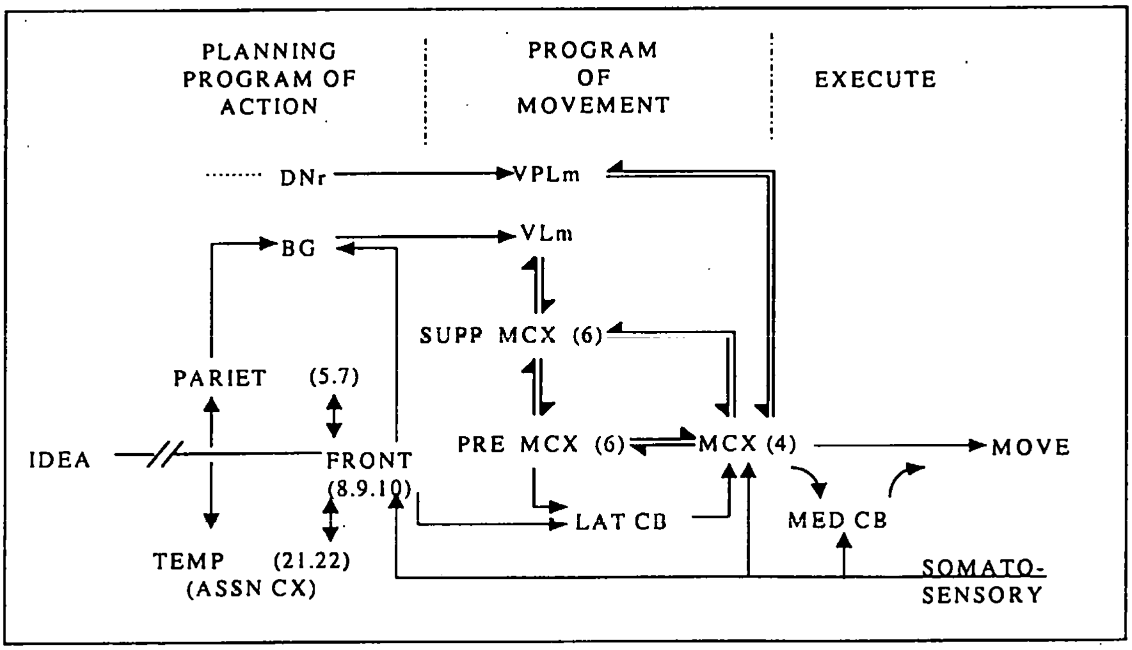


Figure 2-2: Neural pathways for planning, programming and execution of voluntary movement. BG, basal ganglia; DNr, denate nucleus of cerebellum; FRONT, frontal cortex (areas 8, 9, 10); LAT CB, lateral cerebellum; MED CB, medial cerebellum; MCX, motor cortex (area 4); PARIET, parietal cortex (areas 5, 7); PRE MCX, premotor cortex (area 6); SUPP MCX, supplementary motor cortex (area 6); TEMP, temporal association cortex (areas 21, 22); Vlm, medial

part of the ventral lateral thalamic nucleus; VPLm, medial part of the ventral posterior lateral thalamic nucleus. (From Kuehn, D.P., Lemme, M.L., & Baumgartner, J.M., 1989).

This model has been revised and reprinted by several researchers (Hirose, 1982; Eccles, 1982; Netsell, 1982; Kubota, 1984; Barlow, Farley and Baumgartner, 1989). These modifications have proposed a unitary basal ganglia-thalamocortical circuit. In contrast, De Long and Alexander (1987) have suggested segmental circuits with at least one motor loop and an association loop as opposed to the unitary circuit. Alexander, De Long and Strick (1986) and Miller and De Long (1988) proposed a parallel organization of several segmental circuits following observations on the control of voluntary movement. A system of parallel circuits as suggested by Kent (1990) is shown in Figure 2-3.

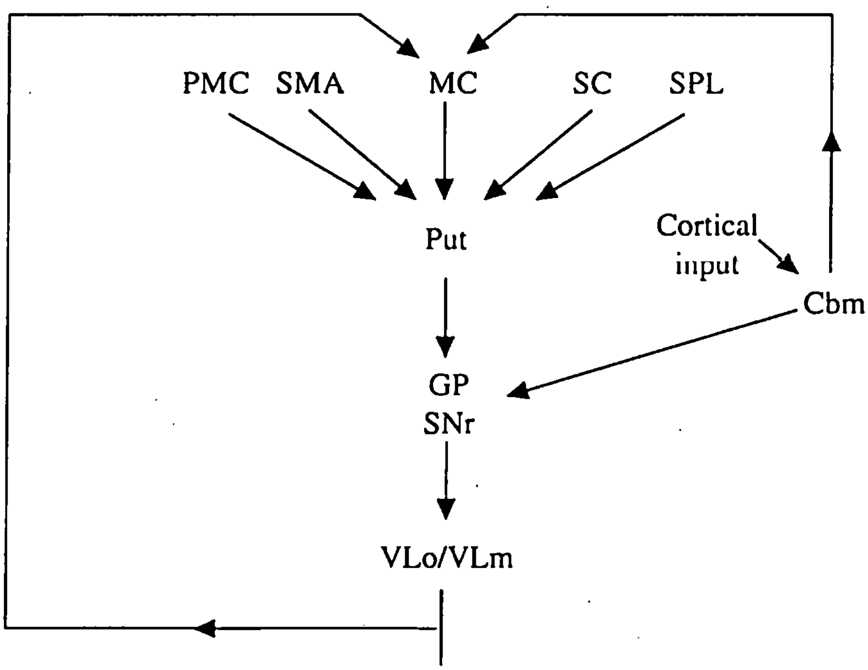


Figure 2-3: A revised model of neural pathways for the control of voluntary movement. PMC, premotor cortex; SMA, supplementary motor areas; MC, motor cortex; SC, somatosensory cortex; SPL, superior parietal lobule; Put, putamen; Cbm, cerebellum; GP, globus pallidus; Snr, substantia nigra pars reticularis; Vlo, pars oralis of ventrolateral thalamus; Vlm, pars medialis of ventrolateral thalamus. (From Kent, R.D., 1990).

In this model the putamen receives partially overlapping projections from five areas of the brain (premotor cortex, supplementary motor area, motor cortex, somatosensory cortex, and superior parietal lobe). These projections are thought to be maintained from the putamen (within the striatum) to the globus pallidus and substantia nigra. Therefore the putamen can be regarded as a centre of convergence of segmental circuits from various cortical regions. It is proposed that the cerebellum revises the motor instructions that are prepared in the motor circuit.

This model of speech production proposes that it is the basal ganglia which are involved in the programming of speech movements and in particular the coupling of sensory and motor information. Kent, Adams and Turner (1988) suggest that this may prepare sensorimotor trajectories to guide the performance of movement. They propose that further elaboration of Allen and Tsukahara's model is necessary to explain the interconnections among various cortical and subcortical sites. These connections are important since they "enable cortical neuronal groups to anticipate the consequences of their own activity and thereby prepare for the next action in a series" (p.36). Edelman (1989) has speculated on structures within the brain which may have a role to play in the regulation of successive actions and their time constants. The suggestions are that the neocortex maintains the long-term pattern of an action series whereas the basal ganglia and the cerebellum are responsible for relatively short time spans. The basal ganglia are involved in aspects of motor programming and sensorimotor coordination whilst the cerebellum is primarily concerned with the control of timing and synchronization of movements. Therefore, various parts of the brain are involved in the control of succession according to time constants of activity.

Kent (1990) relates various neurological disorders to this model of movement control. Of particular interest for this thesis are the explanations relating to conduction aphasia and AOS. For example, conduction aphasia which he states is primarily a disorder of phonetic sequence management and the specification of sensory trajectories, could be the result of a cortical lesion affecting the supramarginal postcentral gyrus (a centre lesion) or the arcuate fasciculus. He also suggests that Figure 2-3 is also compatible with AOS. Whilst he recognizes that the neural lesions responsible for this disorder are usually believed to be pre-rolandic in the vicinity of the third frontal convolution he notes that subcortical lesions have also been associated with the disorder. He suggests that a lesion at several points along the "motor" loop could be responsible for problems involving motor selection, sequencing and programming. Kent believes that many of the errors that are considered to be characteristic of AOS as suggested by Darley (1982) can be seen in normal speech (especially errors of sequencing). Kent (1990) suggests that these errors are just more prevalent in apraxic speech. He concludes that "The emerging picture of apraxia of speech is one of a combination of disturbances at various levels, minimally the phonological and motoric levels" (p.390).

A model of spreading activation may be able to explain the multi-level character of the errors. Such a model is described below.

2.6.2 A functional model of speech production

A single connectionist model of speech production is reviewed. The model chosen is Dell's model of spreading activation (Dell 1980, 1985, 1986, 1990). There were several reasons for choosing this model of speech production:

1. Whilst models involving interactive spreading activation (ISA) as applied to speech production are not new, Dell's model has been tested by computer simulated studies and developed in the light of these.
2. Dell has used the idea to explain in detail phonological encoding in speech production.
3. The model is capable of accounting for many normal speech errors, for example, slips of the tongue.
4. Recent research has suggested that a theory of ISA can explain the origins of paraphasic errors (Martin, Dell, Saffran and Schwartz, 1994).

This section aims to:

1. Outline the theory of ISA and describe a model of phonological coding within this framework.
2. Describe certain characteristics of normal speech errors which the model is capable of explaining.
3. Highlight normal speech error phenomena which is not accounted for by the model.
4. Speculate on the origins of paraphasia in deep dysphasia as suggested by Martin, et al. (1994).

Whilst earlier models of speech production advocated that lexical retrieval was a single stage process (Oldfield 1966a, Oldfield 1966b, Brown and McNeil 1966, Forster 1976) most current theories are in agreement that lexical access involves two stages, an abstract or semantic stage and a phonological stage. Normal speech errors have been the principle data for the development in models of speech production and the support for the necessity to include two stages. Errors can be categorized into two main types, one suggestive of difficulties at a semantic level (e.g. "he is drinking the sandwich") and the other at the phonological level (e.g. "tambourines" → "trampolines"). The relative timing of these two stages has been important in the development of recent models of speech production. Some researchers believe that there is an overlap in the temporal arrangement of stage one and stage two (Dell, 1986; Stemberger, 1985) such that processes at both stages are inextricably linked in time. Others suggest that the two stages are completely separate (Butterworth, 1992; Levelt et al., 1991; Garrett, 1980, 1982) and that the first stage must be complete before the second can commence.

ISA is a connectionist view of speech production which assumes the use of positive feedback from later to earlier levels. Since the focus of this thesis is on the production of speech sound errors only the processes involved in phonological encoding and not sentence production will concern us. Dell (1986) defines phonological encoding as "the process by which the speech sounds that compose a morpheme or a string of morphemes are retrieved, ordered and organized for articulation" (p.293). Dell (1985) suggests that a rudimentary network for phonological encoding process may consist of the following three levels: morphemes; phonemes; and phonemic or phonetic features. A more detailed account is shown in Figure 2-4. Each level is composed of nodes which stand for a particular word or part of a word. Top down primary connections link the nodes from a higher level to a lower level (e.g. morpheme to phoneme) and bottom up connections enable positive feedback to influence production. Dell (1985) suggests that the feed forward and feedback connections between the levels "enables the nodes for a single morpheme and its phonemes and features to act as a mutually forming coalition" (p.6-7). He believes this feedback edits out many potential production errors.

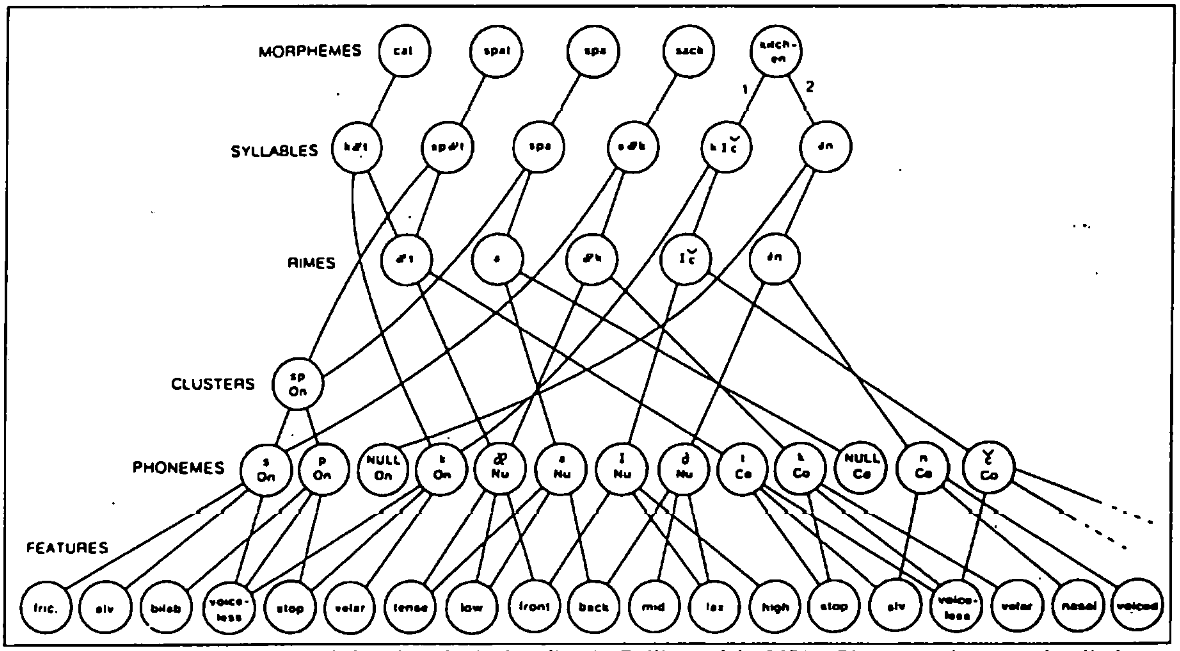


Figure 2-4: A piece of a network for phonological coding in Dell's model of ISA. Phoneme, cluster and null element nodes are labeled as to whether they are potential (On)sets, (Nu)clei, or (Co)das. All connections are top-down and bottom-up. (Taken from Dell, 1986).

Dell (1986) states that the "defining components of spreading activation are *spreading*, *summation*, and *decay*" (p.287). Spreading occurs when a node has reached an activation level greater than zero and a proportion of this spreads to the nodes at a lower level to which it is connected. Summation is defined as the adding of the spreading activation to the destination node's current level of activation. Finally, decay is included in the model to keep the levels of activation down following spreading and summation and is a passive function. These three components apply to all the nodes in the lexical network.

2.6.2.1 A model of phonological encoding

In Dell's ISA model (1980, 1985, 1986, 1990) phonological encoding consists of the mapping between the morphological representations and a phonological representation. He proposes that the phonological representation is phonemic rather than phonetic since when sounds are misordered they acquire the allophonic characteristics which are appropriate for their new position in the word (Fromkin, 1971). The model assumes that the morpheme level is always a single CVC syllable. Since not all morphemes will have an initial or final consonant, special nodes for null elements are included (e.g. "egg" would require a null element in onset position since there is no initial consonant). This has the effect of simplifying phonological rules. Dell also includes a special node for syllabic position encoding since a unit that can occur in more than one position must be represented by more than one node. For example in a word such as "kick" the initial /k/ is represented by a different node to the final /k/. This position encoding explains why during misordering of speech sounds initial and final consonants rarely substitute for each other (Shattuck-Hufnagel 1979).

There are four stages of processing in the network which are detailed below:

2.6.2.2 Input

At this stage the intended morpheme is assigned current node status and its activation level is incremented by an arbitrary amount (100 units). Also at this stage, upcoming morphemes are primed although the activation level for the subsequent morphemes is lower (50 units). This anticipatory activation represents the ongoing processing at higher levels.

2.6.2.3 Spreading activation

A node sends a fraction of its activation to all nodes directly connected with it. This occurs during a given time period which Dell calls a "time step". When this activation reaches its destination it combines with the current level of activation thereby raising it due to the excitatory nature of the connection. If this process were to continue then the activation level for a given node could increase infinitely. To prevent this and to limit the growth of activation there is a passive decay mechanism built into the model. Therefore all nodes lose some fraction of their activation during each time step. There are no thresholds, saturation points or linearities within the model so the passive decay mechanism prevents activation levels from becoming too great.

Dell provides a rule for the spread of activation for the period of one time step.

$$V_1 = \left[V_0 + V_0(pM)\right]\left[(1-q)I\right]$$

where p – the fraction of activation sent during each time step, q = the fraction of activation lost at each time step, V_0 = the vector containing the activation levels of all nodes at a certain time and V_I contains the same after one step has passed. M is an n x n matrix of 1's and 0's where 1 indicates a connection from node i to node j and I is the n x n identity matrix.

2.6.2.4 *Decision stage*

After a certain number of time steps (speaking rate = parameter *r*) a single syllable is selected according to the phonological rule

syllable → Onset Nucleus Coda

The onset and coda may consist of a null element, a consonant or a consonant cluster. The node with the highest activation level is then tagged. The phonological rule allows strings of sounds which either occur or do not occur in the language to be selected.

2.6.2.5 *Post decision clean-up*

The final stage concerns two parts for allowing the process to continue. Firstly, the activation level of the selected phonemes returns to zero. The purpose of this function is to prevent perseveration of phonemes. Second, the next morpheme in the sequence planned becomes the intended morpheme and so the process returns to the input stage, it is assigned current node status and its activation level is increased to 100 units.

2.6.2.6 *Speech error phenomena explained by Dell's model of ISA*

Research into the study of speech errors has identified the following phenomena which can be explained by an ISA model of speech production:

1. Lexical bias.
2. Repeated phoneme effect.
3. Proportion of anticipatory to perseveratory exchange errors during the production of tongue twisters alters with practice.

2.6.2.7 *Lexical bias*

Lecours and Rouillon (1976) conducted computer simulated experiments of segmental substitutions which created real words. They concluded that form-related word errors in jargon aphasics were simply sound substitutions that happened to create real words. However, evidence from speech error literature has proven that this occurs at a greater than chance level and therefore there must be some lexical bias. Dell provides an explanation in terms of an ISA model of speech production. He believes that the lexical bias is a direct result of spreading activation from a later level (phonological) to an earlier level (word). The feedback loops that result increase the likelihood of an error which is a morpheme over those creating phonologically legal but non morphemic strings. Lexical bias is related to rate of speech (parameter *r*). As the speech rate increases the lexical bias effect will decrease. Three time steps are necessary to create lexical bias (Dell, 1985). The first time step allows the morphemic input to reach the phonemes, the second allows phonemic activation to feed back to the morpheme level and the final step allows the effects of this feedback to be transmitted. At a fast rate of speech the anticipatory thresholds for a morpheme do not differ from a non morpheme and therefore no lexical bias will take effect. Dell (1986) describes a hypothetical example for the word "kitten" where for some unspecified reason the phoneme node for a /d/ is highly activated in onset position. At a slower speaking rate Dell proposes that bottom-up feedback from the sound to the morpheme level will increase the activation of morphemes (e.g. "kitten", "mitten") over non-morphemic phonologically legal strings (e.g. "ditten"). Subsequently this will activate the phoneme nodes for /k/ and /m/. The result is that sound(s) which are not compatible with a single morpheme will be edited out such that a morpheme is produced. However, if an /m/ as opposed to the /d/ had been mistakenly activated it is less likely that it would have been edited out since the production of the nasal would have resulted in a morpheme. Therefore, bottom-up feedback will reduce some errors but encourages others by activating words and morphemes which have segments in common with the target.

Dell (1986, 1990), using a technique for eliciting initial consonant misordering errors during computer simulation experiments, has produced this effect in normal speakers. By changing the deadline for producing a response he was able to change the lexical bias effect. The less time that was available for the response and subsequent rate of speech resulted in the production of more non-word errors. However, Bloch (1986) found similar errors in his investigation of a jargon aphasic where the speech rate was not increased as part of the experimental procedure. Therefore factors other than the rate of speech must be responsible for the lexical bias effect. Dell used computer simulation experiments to alter the strength of connections between nodes. In the ISA model described a decrease in connection strength would result in a slower spreading of activation and therefore more time would be necessary for the activation to reach the correct nodes. Dell was able to show that increasing the connection weights increased the lexical bias effect. Dell suggested that for Bloch's (1986) jargon aphasic the connection strength must have been pathologically altered since the rate of speech was normal.

2.6.2.8 Repeated phoneme effect

The repeated phoneme effect (MacKay, 1970, Wickelgren, 1969) can be attributed to the bottom-up processes in the ISA model. It states that two sounds are more likely to be involved in an error if their neighbouring sounds are identical. The example quoted by Dell (1985, 1992) concerns the phrases "deal back" and "deal beak". Studies of normal speech production have shown that "deal" is more likely to slip to "beal" in "deal beak" than "deal back". Dell's explanation for this occurrence is due to the words "deal" and "beak" sharing the same vowel node /i/. When "deal" is the activated morpheme and "beak" the primed morpheme the vowel node acts as a pathway for activation to spread between the two morphemes. The effect is the equalization of activation levels of the two morphemes thereby increasing the chance for an error to occur. This phenomenon, like the lexical bias effect, is dependent upon rate of speech, that is it is not evident at a fast speech rate because there are not enough time steps for phoneme to morpheme feedback.

2.6.2.9 Perseveratory versus anticipatory speech errors

It has been noted that normal speakers tend to make more perseveratory speech sound errors during initial recitation of tongue twisters than anticipatory errors. However, with practice the proportion of these two error types is reversed. Jordan (1986) and MacKay (1987) believe that this can be explained by suggesting that practice strengthens the connections between nodes in models of ISA. Schwartz, Saffran, Bloch and Dell (1994) examined the shift in error patterns produced by normal speakers learning to say tongue twisters and also re-examined data gathered by Bloch (1986) from a jargon aphasic speaker. The hypothesis they tested was that "production systems operating at lowered efficiency not only make more errors, but a particular pattern of errors: errors that favor perseverations and the production of non words and other familiar strings" (p.58).

Schwartz et al. (1994) identified perseveration in a jargon aphasic's speech at the expense of anticipations. They termed perseverations "bad" speech error patterns and found that this type of error was also seen during normal speakers first attempts at tongue twisters. They proposed that practicing these phrases would have two results: a decrease in the number of errors produced; a change in the error patterns with more anticipatory ("good") errors compared to perseveratory. Their reasoning behind this concerned connection strength. They suggested "bad" errors were a result of weak connections which made the system erroneously stick since words that had previously been encoded would dominate over upcoming records. In their experiment in which normal speakers practiced tongue twisters they found that this rehearsal altered error patterns in two ways: the initial predominance of perseveratory over anticipatory errors was reversed; with practice there were more errors creating familiar strings of phonemes. Schwartz et al. (1994) concluded that "..... practice, speech rate and brain damage appear to have ...... complementary effects on retrieval processes in language production" (p.79). A slower rate of speech allows sufficient time for the spread of activation, practice will increase the weight connections whereas brain damage appears, at least for the jargon aphasics they studied, to decrease connection strength.

2.6.2.10 Normal speech error data not accounted for by the ISA model of speech production

Dell (1986) identified five error phenomena which could not be accounted for by the model proposed. However, he suggested modifications to his basic ISA model which could explain these.

2.6.2.11 Initialness effect

Stemberger (1982) suggested that the initial sounds of words or syllables slip more often (80%) than other parts of the words. However, he also noted that this may not be a true reflection of the percentage of errors involving initial consonants but because errors are easier to detect in word initial position. Therefore this observation may be a perceptual bias effects. If there is an initialness effect it is not accounted for by the ISA model proposed here. Dell (1986) suggests that this phenomenon could be explained by modifying the model to allow initial consonants to have greater connection strength than non initial. He proposes that this increased strength is a result of initial sounds becoming highly activated more easily. The increased strength is then associated with increased variability for initial sounds.

2.6.2.12 Triggering effect

For some sound errors a nearby trigger or source can often be identified. For example, a deleted sound may have occurred in the previous morpheme. But Dell's ISA model proposes that repeated sounds tend to keep a node activated and therefore deletion of a phoneme would be unlikely. The example he gives is the phrase:

piano sonata number → piano sonata umber

The word initial (WI) /n/ in "number" has been omitted suggesting that a WI null node has higher activation than the target. If some form of inhibition was introduced into the ISA model then this would account for the triggering effect.

2.6.2.13 Effects of vocabulary type

It is generally accepted that sound errors affect content words more often than function words (Garrett, 1975; Stemberger, 1984b). This effect is not accounted for in the ISA model since all words are treated alike during phonological encoding. However, Dell (1986) suggests that since function words are used more frequently than content then the addition of frequency sensitive resting levels to the model would explain this phenomenon. Therefore, function words would have resting levels of greater than zero and higher than content words.

2.6.2.14 *Violations of the syllable position constraint*

Since the process of phonological encoding generates categorized slots there is a rule within the ISA model that a misordered sound must retain its syllabic serial position.. As the model stands there appears to be no flexibility so violation of the syllable position constraint is impossible. Dell (1986) states that this arrangement has two weaknesses, one empirical and one theoretical. The former concerns examples where there are violations of the syllable position constraint, even if these are rare. Stemberger (1982b) found 21.4% within word errors and 1.6% of between word errors defied this constraint. The theoretical weakness concerns the position labeling of different nodes for sound units. As it stands the model believes that the /t/ in "tick" and "hat" are different sounds with different nodes. Dell suggests that by eliminating the position encoding for feature nodes but retaining it for phoneme and cluster nodes, both theoretical and empirical problems are overcome. This means that onset and coda /t/ are different but can share features. He believes that this modification would "create a slight tendency for violations of the syllable position constraint" (p.313). Alternatively, entire elimination of position encoding but the introduction of position binding nodes would allow explanation of any violations of the constraint.

2.6.2.15 *Null elements and the need for network control of phonological frames*

In simulation experiments there is a tendency for consonants to be deleted or more specifically replaced by a null node. This is in fact the reverse of what is found in naturally occurring speech errors where addition is more common. The intrusion of null elements in the model is believed to originate from their high syllabic frequency. Dell proposes that if the relationship between the lexical network and phonological frames could be specified without the need for null elements then the problem would be overcome. He suggests form related lexical nodes to guide construction instead of the repetitive generation of CVC structures which would have the effect of adding dependencies between syllable and metrical structures. For details of this the reader is directed to Dell (1986).

Whilst the basic model as outlined in this section has certain limitations, Dell has proposed modifications to the original version in an attempt to overcome these. It would appear that the changes advocated explain certain error phenomena which has been noted in the literature.

2.6.2.16 *The origins of paraphasia in deep dysphasia as accounted for in Dell's ISA model of speech production*

In their paper, Martin et al. (1994) considered connection strength and decay rate in trying to map aphasic disorders onto the model. Coupled with the rate of speech, these two parameters influence the degree of activation that a target node receives in relation to other competing nodes. Dell (1989), in distinguishing "bad" errors and "good" (anticipatory) errors noted the importance of connection strength suggesting that an increase in connection strength gave rise to more "good" errors. However, Martin et al. (1994) believe that a decrease in connection strength is not enough to account for the paraphasic errors found in aphasic speech. Specifically, they propose that a decrease is not sufficient to generate a high enough rate of paraphasias. Whilst a reduction in connection strength throughout the network may well lessen the chance of selecting a target, it does not follow that it will increase the chance of selecting a phonologically related node. This is because an overall reduction in connection strength would also reduce the spread of activation to these phonologically related nodes. They propose that two conditions are necessary for an increase in formal paraphasias. One of these involves connection strength. This they state would have to allow priming at levels of representation supplying feedback to phonologically related nodes. The second involves the relative levels of activation of target nodes and their competitors. They suggest an unspecified alteration to reduce the usual advantage that the target has. If the rate of decay increased at all levels the resulting outcome would be a shift in the relative activation levels of all nodes. Therefore, they tested the hypothesis that rapid decay could produce an increase in formal paraphasias by computational simulation. The increase in decay would not affect the priming of a target node or phoneme nodes connected to it, but it would affect the summation of the original activation and activation provided by feedback from the phoneme level. The effect of this would be to decrease the advantage held by the target node subsequently increasing the likelihood of competitor selection since they are activated later than the target. The simulation experiment showed two effects. The first was a general amplification of error tendency. However, Martin et al. (1994) point out that this would be true of any change which lowered the activation levels and was not specific to an increase in decay rate. The second effect was the production of a greater percentage of formal paraphasias in naming which was specific to the alteration of decay rates.

2.6.3 Summary

Two distinctly different models of speech production have been outlined in this section. The data collected from this investigation will be discussed in relation to these in Chapter 8. Specifically can these models of speech production acount for the speech errors in aphasic speech?

Chapter 3

3. Methodology

3.1 Introduction

This chapter will cover the following:

1. The test material recorded for the pilot and the main investigation.
2. The instrumentation and recording conditions.
3. Methods of data analysis, EPG and acoustic.
4. A description of the subjects who participated in the study, the rationale for their inclusion and details on their speech and medical condition.

3.2 Test Material

3.2.1 Pilot study

A pilot study involving one aphasic speaker was conducted to refine the test material and experimental procedures. The pilot test material consisted of forty-seven single words, four repetitions of four words at a slow and a fast speaking rate, eight sentences constructed by the subject, eight sentences to be read and a non-verbal task. Following administration of the pilot recording the corpus was refined. The test material is detailed in Section 3.2.2 below.

3.2.2 Test material

The main investigation included the following test material:

1. Forty-seven single word items were arranged into two lists (see Table 3-1). List A contained the lingual consonants of English in a variety of phonetic environments and in word initial (WI) and word final (WF) position. Word list B contained sequences of consonants which varied in their degree of complexity. These sequences were both within a single morpheme and across morpheme boundaries. Both word lists were adapted from those used by Hardcastle et al. (1985) in their study of adult dysarthric and verbal dyspraxic speakers. All items were presented to the subject on flash cards which had both a pictorial representation of the word specially constructed for this study and the written form. Each word was prefaced with either the indefinite ("a") or definite ("the") article. Two repetitions of each word list were recorded.
2. Ten repetitions of the words "deer", "clock" and "kitkat". These words were chosen because they varied in articulatory complexity.
3. The subject was required to construct 8 sentences from the following words selected from word list B: "catkin", "weekday", "tractor", "deckchair", "headlight", "cocktail", "kitkat" and "clock".
4. Eight sentences using the same words as 3 above were constructed by the researcher and presented on cards for the aphasic speaker to read (see Table 3-2).
5. A non verbal protocol was included to assess whether speech and oral non-verbal movements are related to common underlying neurophysiological and neuropsychological processes. The following sequences were each produced ten times in succession with and without voice and at fast and slow rates: tongue tip to alveolar ridge; tongue dorsum to soft palate; alternating alveolar-velar contact.

	Word list A
1.	a dart
2.	a tip
3.	a leg
4.	a deer
5.	a chain
6.	a shark
7.	a key
8.	the dolls
9.	a gear
10.	a book
11.	a car
12.	a beak
13.	a knot
14.	the dark
15.	a tick
16.	near
17.	the sea
18.	she
19.	a tear
20.	the sun
21.	a mouse
22.	a cheer
23.	a fish
24.	a zoo
25.	a sheep
26.	a brush
27.	a leer
28.	a seed
29.	a shop
30.	a racer
31.	a leaf

	Word list B
1.	a cocktail
2.	a kitkat
3.	a clock
4.	a headlight
5.	a tractor
6.	a weekday
7.	a tickling
8.	a deckchair
9.	the witchcraft
10.	a bookshop
11.	a star
12.	a box
13.	the hats
14.	a squashkit
15.	a skirt
16.	a catkin

Table 3-1: Word lists A and B.

	Sentences
1.	I saw a catkin in the tree
2.	Tuesday is a weekday
3.	The lad was sitting in the tractor yesterday
4.	I sat in the deckchair on the beach
5.	The headlight is definitely broken
6.	I'd like a cocktail please
7.	My favourite biscuit is a kitkat
8.	The hands on the clock have stopped

Table 3-2: Sentences read by each subject.

Due to the large amount of data that EPG generates, only analysis of single words from word lists A and B and the repetition task are reported in this thesis. Sentences will not be reported in this dissertation. Methodological difficulties prevented comparison of data from the non-verbal tasks, for example, not all of the aphasic speakers were able to comprehend purely motoric based (non-linguistic) instructions. Some subjects needed speech orientated directions to perform the tasks. For example, "place your tongue behind your teeth as if you were going to say [ti]. Now make the movement without the sound".

3.3 Instrumentation And Recording

The latest Reading electropalatography system (EPG3) was used to record the timing and location of the tongue with the hard palate during continuous speech. This procedure will be summarized below but a more detailed description of the system can be found in Hardcastle, Gibbon and Jones (1991).

3.3.1 The artificial palate

Each subject was fitted with a custom made artificial palate following a full impression of their upper teeth and palate. The palate is made of acrylic, approximately 0.8mm thick, into which 62 silver electrodes, 1.4mm in diameter, are embedded. The electrodes are arranged into eight horizontal rows with eight electrodes in each row except row 1 (most anterior) which has six (see Figure 3-1). Placement of the electrodes follows a predetermined scheme of anatomical landmarks which specifically target phonetically important areas. For example, the region near the junction between the hard and soft palate and the lateral margins close to the side teeth (for details see Hardcastle, Morgan-Barry and Clark, 1987). The palate can be divided into three zones: alveolar region (rows 1 and 2); palatal region (rows 3, 4 and 5); and velar region (rows 6, 7, and 8) (see Figure 3-2). Each electrode is joined to a piece of enamelled copper wire (41swg) and channelled to the posterior corners of the palate. Here they are covered in a soft heat shrinking tubing and emerge from the mouth via the buccal surfaces of the maxillary dentition. All palates were made by the firm Broughton and Tyrrell, Newbury (UK).

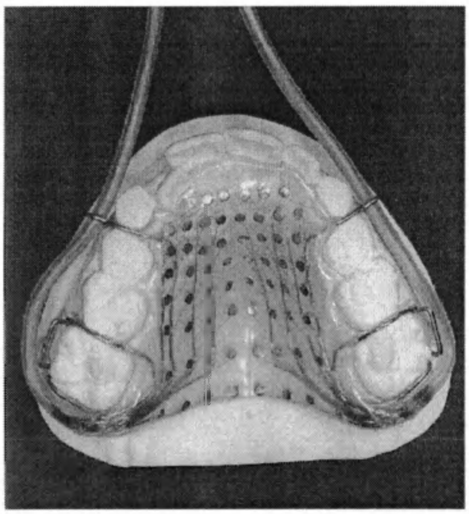


Figure 3-1: EPG palate and dental impression.

000000 000..000	Alveolar
0.....00 0......0 0......0	Palatal
0......0 0......0 0......0	Velar

Figure 3-2: Division of the palate into zones.

3.3.2 EPG 3

This system ran in conjunction with an IBM 486 PC. During the operation the subject wears the palate which is plugged into a multiplexer unit worn around the neck. This has an output for a small electrode which the subject must hold to create a circuit. This hand held electrode provides a small sinusoidal signal with a magnitude of 300mV RMS at a frequency of about 15kHz. The 62 electrodes are scanned by electronic circuits and contact identified by the presence of a signal. These patterns are then transmitted to the computer for storage and display. The sampling rate of the EPG data is 100 frames per second and the acoustic signal 10kHz. The program allows for synchronization of the speech waveform with the EPG data. The EPG acoustic signal in this investigation was sampled using a Shure (USA) VP88 microphone. In addition, simultaneous digital audio (DAT) recordings were made using a lapel microphone, AT 803B, by audio-technica (Japan) via a microphone preamplifier (Alice Soundtech plc UK) onto a Sony DAT recorder, DTC 60ES. For more details concerning the hardware of the Reading EPG 3 the reader is directed to Hardcastle et al. (1991). The EPG3 system can be seen in Figure 3-3.

Figure 3-3: EPG3 system set-up.

3.3.3 Data collection

Recordings took place in a sound damped studio at Queen Margaret College, Edinburgh. All equipment except the multiplexer was outside the recording studio to minimize extraneous noise during data collection.

Palates were checked by an orthodontist to ensure goodness of fit. Subjects were then instructed to wear their palates for at least 4 hours prior to recordings to ensure that they had become accustomed to the feel of the device in the mouth and that it did not affect their speech.

Recordings were made over consecutive weeks, with sessions usually lasting forty-five minutes to an hour. Two recording sessions were usually enough time to complete the test material.

Prior to each recording session the researcher checked the subject's palate to ensure that the palate was fully operational and that there were no loose connections. All test material (except non-verbal tasks) was presented visually on A5 cards. For Word lists A and B and the repetition task a picture of the target accompanied the written word. The material to be covered was rehearsed once to pre-empt any difficulties that might arise during the recording. With the exception of the subject who participated in the pilot study, each subject produced two repetitions of Word lists A and B and a single repetition of the sentences. If the subject indicated that they were not happy with their production the target was re-recorded. The subject was in contact with the researcher throughout the recording and they could see each other through a small window. Details of the recording session were explained during rehearsal and the instructions were repeated verbally to the subject before the start of each section of the test material.

3.4 Data Analysis (EPG)

Initial analysis of the data was by screen display (see Figure 3-4). Where the subject produced more than one production of the target, the final attempt was used for analysis. The EPG patterns are synchronized with the acoustic signal, the left hand cursor relates to the EPG frame in the top left hand corner of the screen. The left and right hand cursors can be moved independently to allow segmentation of the data.

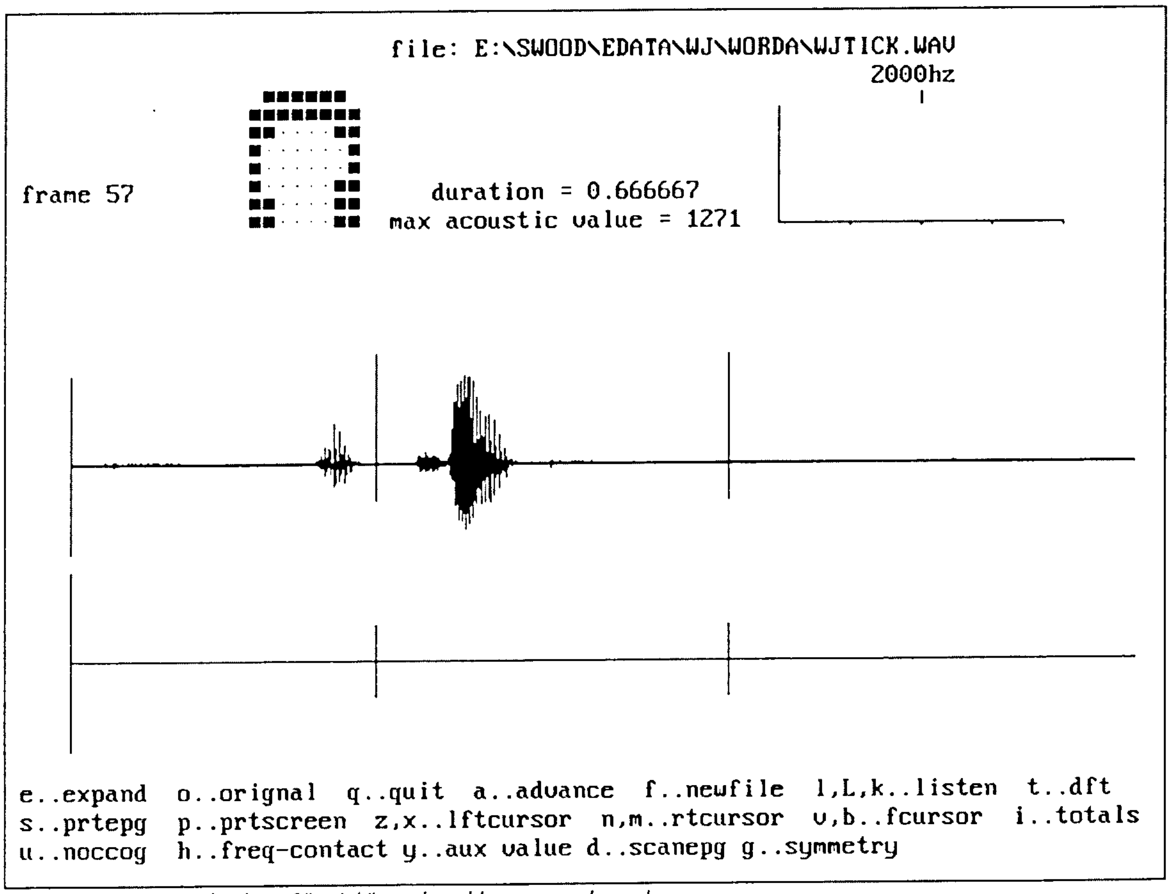


Figure 3-4: Screen display of "a tick" produced by a control speaker.

Print-outs of the EPG sequences between the two cursors is possible. These are read from left to right, each palate shape being 100 msecs apart. Figure 3-5 shows the sequence of lingual/palatal contacts produced by a normal speaker for the phrase "a tick". All data was initially analysed via screen display to detect any abnormal lingual/palatal contacts and unusual sequencing of phonemes.

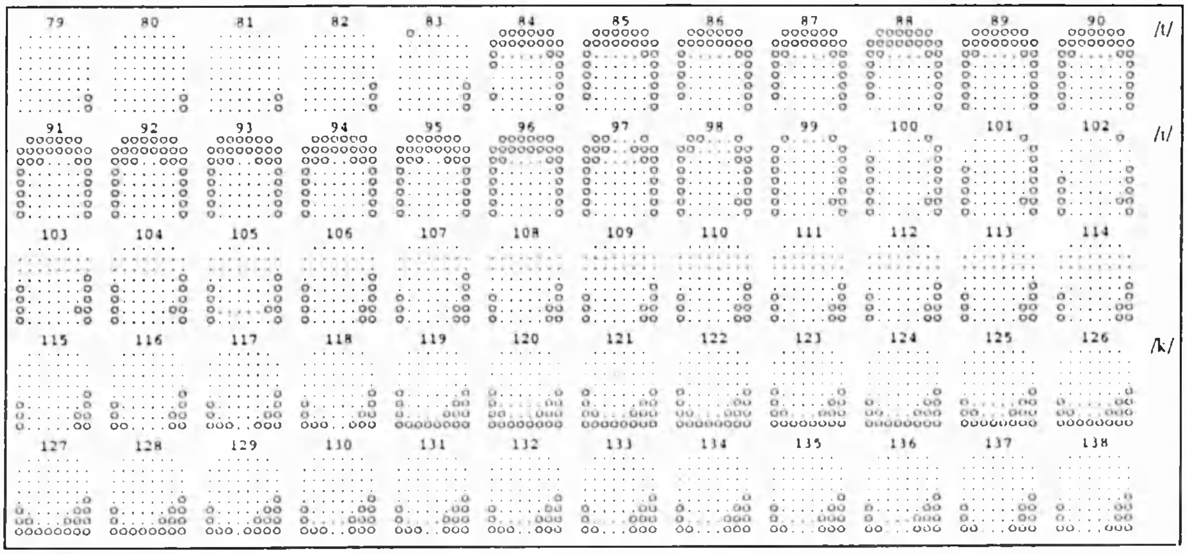


Figure 3-5: EPG print-out of "a tick" produced by a control speaker.

The program allows for other methods of presenting the data. Since these were not employed, they will not concern us here. In addition, an annotation program has been designed which allows the marking of important points along the acoustic waveform (Jones, 1993), for example, the first frame of full closure during an obstruent, the frame of maximum contact, etc. A database was designed using Microsoft Access (version 2.0) into which the annotation points were imported. The database was programmed to calculate various measures. Additionally, the data base was programmed to calculate various indices. The specific measurements reported in this thesis are listed and described in detail below.

3.4.1 Durational measures

Durational measures were made on data gathered from the repetition task. The segmentation and labelling of the three words "deer", "clock" and "kitkat" was based on information from both the EPG data and the EPG acoustic waveform which is detailed in Table 3-3, Table 3-4 and Table 3-5 below.

Annotation point	Description
1	End of periodic pulsing on the acoustic waveform for the indefinite article.
2	First frame of complete constriction at the alveolar region from the EPG trace. In cases of incomplete closure it was identified as the first frame of maximum constriction at the alveolar region.
3	The first frame of maximum contact at the four front rows for the consonant /d/.
4	The last frame of maximum contact at the four front rows for the consonant /d/.
5	Last frame of complete constriction in the alveolar region.
6	The onset of periodic pulsing from the acoustic waveform.
7	The end of periodic pulsing from the acoustic waveform indicating the end of the word.

Table 3-3: Annotation points for "a deer".

The acoustic waveform and EPG print-out identifying the annotation points are shown in Figure 3-6 and Figure 3-7 ("deer"), Figure 3-8 and Figure 3-9 ("clock"), Figure 3-10 and Figure 3-11 ("kitkat").

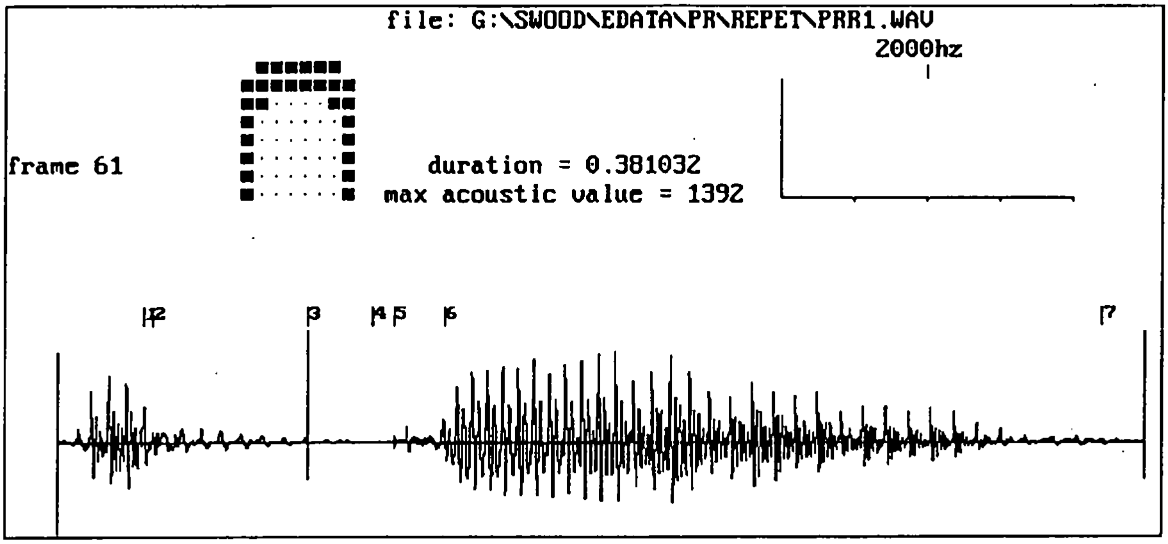


Figure 3-6: Screen display of "a deer" produced by a control speaker. The full acoustic waveform for the target word and the EPG frame at annotation point 3 is shown.

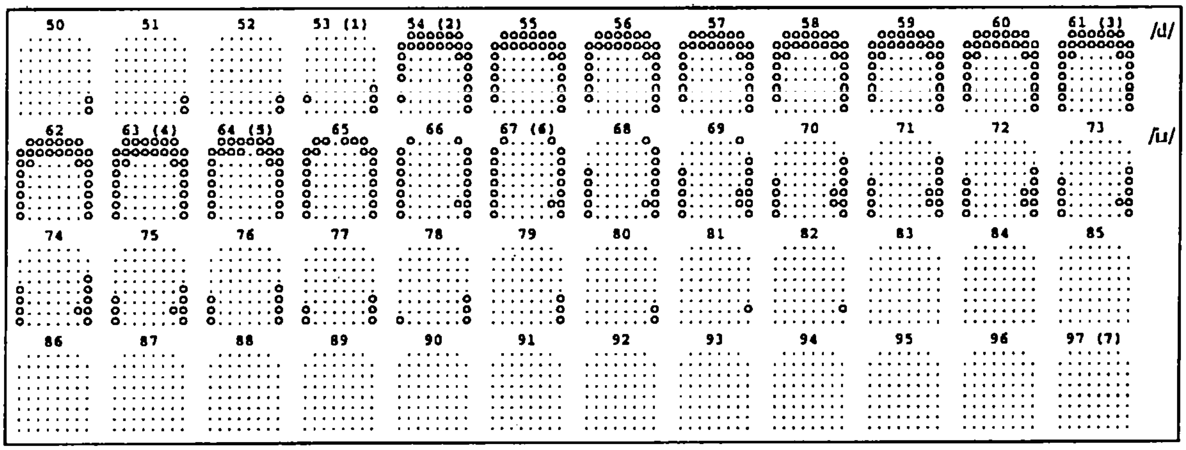


Figure 3-7: EPG print-out of the word "deer" produced by a control speaker. The annotation points detailed in Table 3-3 and shown in Figure 3-6 are marked next to the corresponding frame numbers.

Annotation Point	Description
1	First frame where there was evidence of increased contact in the velar region.
2	Stop Closure for the WI velar stop measured from the EPG or Waveform (SCEW). This indicated the start of velar closure. It was taken as the first frame of full closure in the velar region identified from the EPG trace. In cases where full closure was not seen on the EPG trace, annotation was made from the acoustic waveform. A point soon after the end of regular glottal pulsing for the indefinite article where the EPG contact patterns were relatively stable indicated the start of velar stop articulation.
4	Stop Release for the velar stop measured from the EPG or Waveform (SREW). This indicated the release of full velar closure. If this was not visible from the EPG print-out then the point of release was taken as the burst of energy seen on the acoustic waveform.
5	Approach to Lateral Closure Taken from the EPG trace (ALCE). This was taken as the first frame showing any contact in rows 1 or 2. Where the resulting articulation was felt to be retracted, the first frame with any contact in row 3 was taken to be ALCE.
6	First frame of full or maximum closure for the lateral approximant.
7	Lateral Release taken from the EPG trace (LRE) was taken as the first frame showing release of the full closure in the alveolar region of the palate for the lateral approximant.
8	The onset of periodic pulsing from the acoustic waveform for the vowel.
9	The start of the WF velar closure (same criteria as 2 above).

Table 3-4: Annotation points for "a clock".

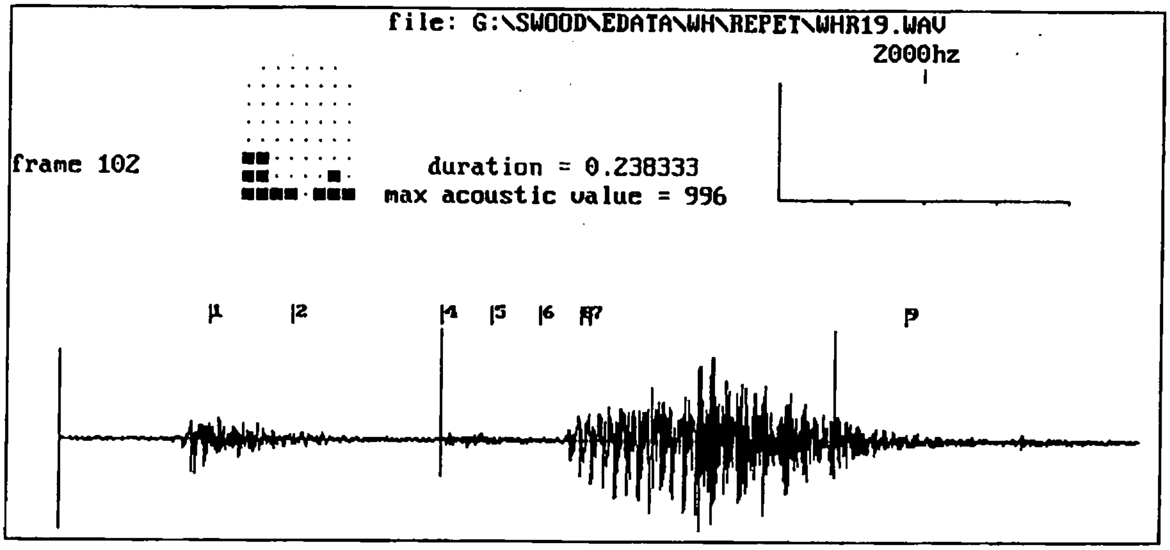


Figure 3-8: Screen display of "a clock" produced by a control speaker. The full acoustic waveform for the target word and the EPG frame at annotation point 4 is shown.

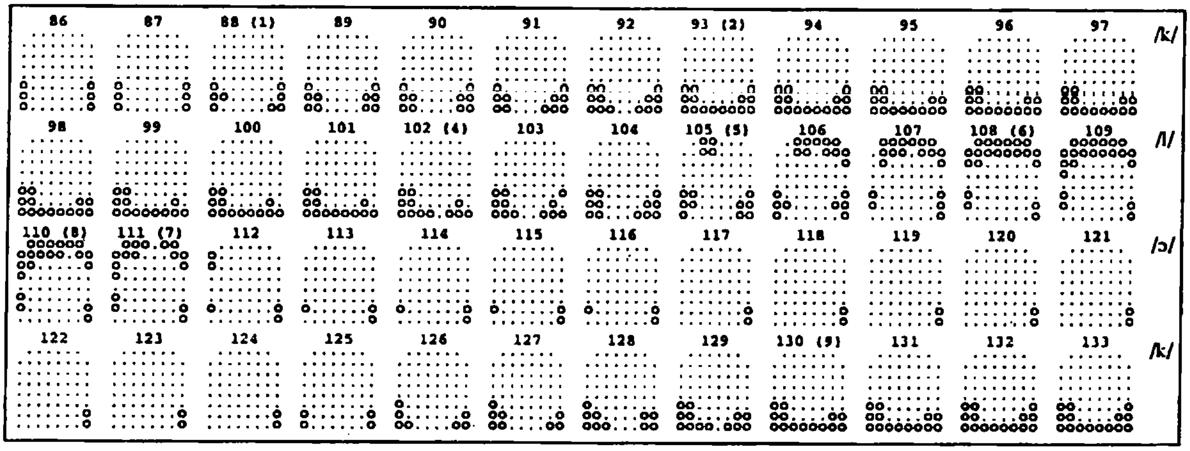


Figure 3-9: EPG print-out of the word "clock" produced by a control speaker. The annotation points detailed in Table 3-4 and shown in Figure 3-6 are marked next to the corresponding frame numbers.

Annotation point	Description
1	First frame where there was evidence of increased contact in the velar region following the indefinite article.
2	This indicated the start of velar closure. It was taken as the first frame of full closure in the velar region identified from the EPG trace. In cases where full closure was not seen on the EPG trace, annotation was made from the acoustic waveform (the same as for "clock").
3	This indicated the release of full velar closure. If this was not visible from the EPG print-out then the point of release was taken as the burst of energy seen on the acoustic waveform.
4	Start of the periodic pulsing for the vowel [ɪ] seen from the acoustic waveform.
5	<u>A</u>lveolar <u>S</u>top <u>C</u>losure as identified from the EPG data (ASC). This was taken as the first frame showing full alveolar closure. If the speaker did not make full closure then the first frame of maximum constriction was taken as ASC. Constriction was not allowed to be greater than 2 electrodes wide to classify as an alveolar articulation.
6	<u>A</u>lveolar <u>S</u>top <u>R</u>elease (ASR). This was the first frame showing release of the alveolar stop closure or constriction.
7	<u>S</u>top <u>C</u>losure for the velar articulation identified from the <u>E</u>PG or <u>A</u>coustic trace (SCEA). It was taken as the first frame of full closure in the velar region identified from the EPG trace. In cases where full closure was not seen on the EPG trace, annotation was made from the acoustic waveform.
8	<u>S</u>top <u>R</u>elease for the velar articulation measured from the <u>E</u>PG or <u>A</u>coustic trace (SREA). If this was not visible from the EPG print-out then the point of release was taken as the burst of energy seen on the acoustic waveform.
9	The start of periodic pulsing for the second vowel.

Table 3-5: Annotation points for "a kitkat".

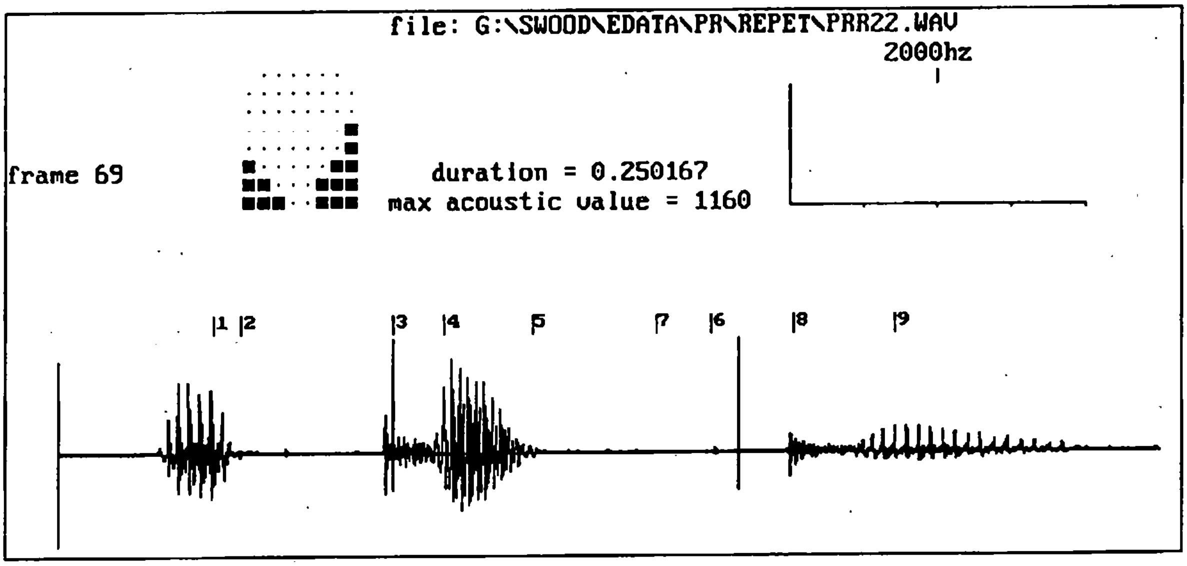


Figure 3-10: Screen display of "a kitkat" produced by a control speaker. The full acoustic waveform for the target word and the EPG frame at annotation point 3 is shown.

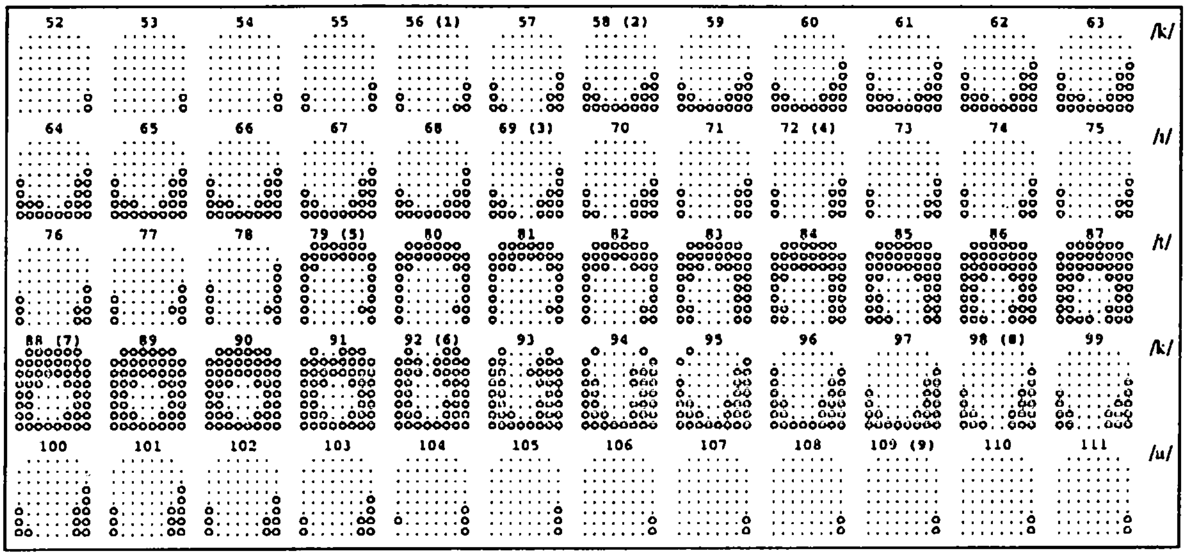


Figure 3-11: Partial EPG print-out of the word "kitkat" with the annotation points detailed in Table 3-5 and shown in Figure 3-10 marked next to the corresponding frame numbers.

The following durational measures were made from the annotation points and the variability over successive repetitions assessed.

1. Duration of the alveolar stop closure in "deer" (time between annotation points 2 and 5).
2. Duration of the /d/ closure in "deer" as a proportion of the whole word.
3. Duration of the WI /k/ closure in "kitkat" (time between annotation points 2 and 3).
4. Duration of the WI /kl/ sequence in "clock" (time between annotation points 2 and 7).

3.4.2 Coarticulation

The sequencing of the WI /kl/ in "clock" and WM /tk/ in "kitkat" were classified according to specific pattern types. For target /kl/ the sequencing patterns identified by Hardcastle (1985), in his study of coarticulation in four normal speakers, were used to describe some of the patterns identified through analysis of the EPG data. Additional pattern types were necessary to classify all the aphasic productions. Hardcastle's (1985) sequencing patterns are detailed in Table 3-6. Additional patterns for the classification of the /kl/ data are given in Table 3-7 and pattern types for the /tk/ sequence in "kitkat" in Table 3-8.

Patterns	Description	Occurrence
Type 1	Release of the /k/ prior to onset of tongue tip/blade movement for /l/.	Favoured at major syntactic boundaries and occasionally word initial cluster environments.
Type 2	Approach to /l/ during the /k/ closure period.	Occurs in word initial clusters.
Type 3	/l/ approach and part of the alveolar closure overlapping with the /k/ closure.	Syllable boundaries within a word and sometimes across a word boundary.
Type 4	Approach of the /l/ occurring prior to the onset of the /k/ closure.	Rare.

Table 3-6: Classification from Hardcastle (1985) summarizing the sequencing of /k/ and /l/ in /kl/ clusters. Typical occurrence for these pattern types as noted by Hardcastle is given.

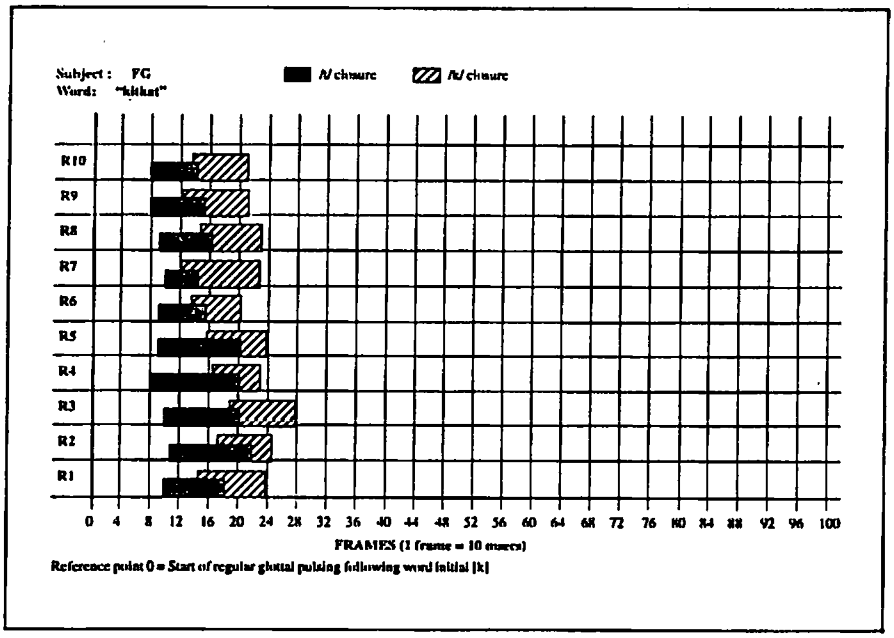
Patterns	Description
Type 5	Single consonant due to omission of one phoneme. This was further subdivided to identify which consonant was missing. Type 5a = omission of /k/, type 5b = omission of /l/.
Type 6	Reversal of the consonants /k/ and /l/ such that the /l/ is articulated and fully released prior to the velar stop closure.
Type 7	The presence of a MAG between the cessation of regular glottal pulsing for the indefinite article and the release of the lateral /l/ articulation.

Table 3-7: Description of the additional sequencing patterns for the /kl/ sequence in "clock" necessary for classification of the aphasic speech production.

Patterns	Description
Type 1	Release of the /t/ closure (ASR) prior to full closure for the /k/ (SCEA).
Type 2	Full velar closure (SCEA) prior to the release of the alveolar stop (ASR) resulting in a double alveolar/velar articulation.
Type 3	Assimilation of the /t/ to the velar articulation such that there was no alveolar contact identifiable on the EPG trace.
Type 4	Full alveolar (ASC) and velar (SCEA) closure commencing at the same time (frame).
Type 5	Full velar closure (SCEW) prior to the alveolar stop closure (ASC) and release of the velar (SREW) after the release of the alveolar stop closure (ASR).
Type 6	Reversal of the /tk/ sequence such that the velar is articulated (SCEW) and released (SREW) prior to full alveolar stop closure (ASC).
Type 7	Omission of the /k/ phoneme.

Table 3-8: Classification summarizing the types of sequencing of the /tk/ phonemes which were observed from the aphasic and control data.

Graphical displays detailing the sequencing were constructed from annotation points SCEW, SREW, ALCE, and LRE for "clock" and points ASC, ASR, SCEA and SREA for "kitkat". The extent of coarticulation of the /k/ and /l/ phonemes in "clock" and the WM /t/ and /k/ in "kitkat" was observed from graphs which indicate the duration of each individual phoneme and their temporal organization. The graphical display for the word "kitkat" indicating the sequencing patterns produced by FG (control speaker) is given in Graph 3-1.



Graph 3-1: Graph to show the temporal arrangement of the /t/ and /k/ phonemes in "kitkat" produced by a control speaker (FG).

3.4.3 Spatial variability

The variability of lingual/palatal contacts during production of the WI alveolar stop closure in "deer" and the WI velar stop closure in "kitkat" was assessed. The variability index (VI) devised by Farnetani and Provaglio (1991) enabled comparison of the lingual/palatal contacts over the ten repetitions. A single frame which identifies a fixed point in the speech signal is chosen. For the alveolar closure in "deer" this was chosen as the frame of maximum contact (annotation point 3) because this is an easily identifiable point made by both control and aphasic speakers. The first frame of velar closure in "kitkat" (annotation point 2) was chosen because this was a consistent gesture made by both groups of speakers. A later point such as the frame of maximum closure sometimes included erroneous alveolar contacts for aphasic speakers. The formula for the VI is given below. The calculation gives an EPG prototypical frame where the higher the index the greater the variability. This is computed from percent frequency of activation of each electrode across several repetitions of the same item. The index is then calculated by summing the differences between a given frequency and 100 (for electrodes with frequencies higher than 50%) and differences between a given frequency and 0 (for frequencies up to 50%), then averaging either over the total area (dividing by 62) or the activated area. The former, that is averaging for the total area, was used in this investigation. This was chosen since the production of a phonemic paraphasia for example may result in contacts over a different portion of the palate to the target (e.g. t/k substitution). If the activated area had been used in the calculation then different areas of the palate would be compared if a paraphasia had been produced. For more details on the variability index the reader is directed to Farnetani and Provaglio (1991).

$$\text{Electrode Variability} = \left(\left(\frac{\text{no. repetitions when electrode is active}}{\text{total number of repetitions}}\right) * 100\right)$$

$$\text{Computed Index Differences} = \begin{array}{l} \text{if Electrode Variability} <= 50 : \left|\text{Electrode Variability} - 0\right| \\ \text{if Electrode Variability} > 50 : \left|\text{Electrode Variability} - 100\right| \end{array}$$

$$\text{Absolute Variability} = \frac{\sum_{i=1}^{\text{total electrodes on palate}} \text{Computed Index Differences}}{\text{Total No. Electrodes On Palate}}$$

The Access database allowed variability to be displayed diagramatically. Again a single reference point was chosen (the same as for the VI). Figure 3-12 shows annotation point 2 over the ten repetitions of "kitkat" produced by a control speaker. The prototypical frame corresponding to these repetitions which summarizes the contacts is shown in Figure 3-13. Each square represents a single electrode, the shading (taken from the electrode variability calculation above) indicates the number of times an electrode was contacted over ten repetitions as a percentage. The figure in each square is the actual number of times the electrode was contacted. Dark or clear areas indicate consistent contact or no contact respectively over the ten repetitions.

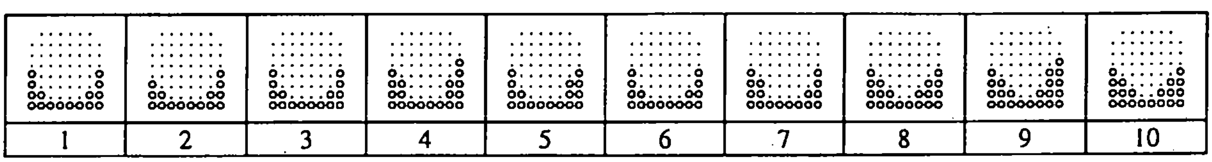


Figure 3-12: Ten repetitions of annotation point 2 for the word "kitkat" produced by a control speaker.

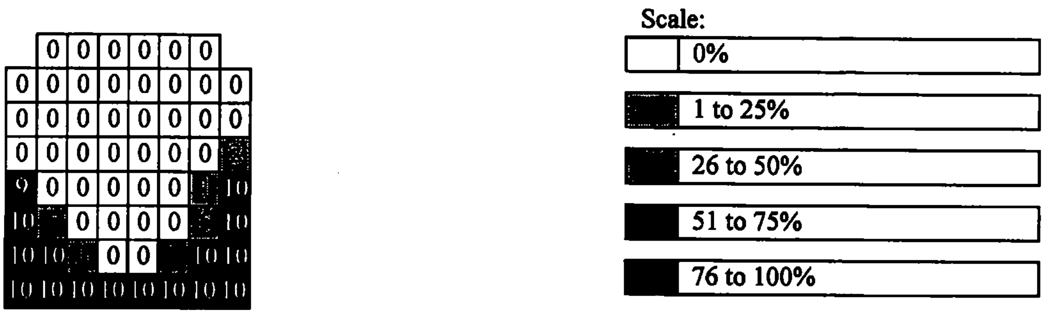


Figure 3-13: EPG palate indicating the number of times each electrode was activated over 10 successive repetitions. The reference frame is annotation point 2 of "kitkat" produced by a control speaker.

The following is a worked example of the calculation for Electrode Variability and Absolute Variability for the frame shown in Figure 3-13 taken from the equation shown above.

Electrode Variability for the first electrode in the fifth row (reading from left to right) in Figure 3-13 was calculated from:

$$\text{Electrode Variability} = \left(\left(\frac{9}{10}\right) * 100\right)$$

Absolute Variability for the whole frame was calculated from:

$$
\begin{array}{lr}
\text{Absolute Variability} = & \text{Row} \\
(\,|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+ & 1 \\
|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+ & 2 \\
|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+ & 3 \\
|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|20-0|+ & 4 \\
|90-100|+|0-0|+|0-0|+|0-0|+|0-0|+|0-0|+|10-0|+|100-100|+ & 5 \\
|100-100|+|50-0|+|0-0|+|0-0|+|0-0|+|0-0|+|50-0|+|100-100|+ & 6 \\
|100-100|+|100-100|+|30-0|+|0-0|+|0-0|+|30-0|+|100-100|+|100-100|+ & 7 \\
|100-100|+|100-100|+|100-100|+|100-100|+|100-100|+|100-100|+|100-100|+|100-100|\,) & 8 \\
\div\ 62 = 3.23 &
\end{array}
$$

3.5 Data Analysis (Acoustic And Perceptual)

Narrow phonetic transcriptions were made from DAT recordings of all the items in word lists A and B and the thirty words from the repetition task using the International Phonetic Alphabet (IPA) (revised to 1993) and extended IPA symbols (revised to 1994) (see Appendix A). The perceived articulations were compared to the EPG data. Of particular interest was whether certain lingual/palatal contacts were detected auditorily. Spectrograms were made of certain items where the EPG patterns did not correspond to the phonetic transcriptions by digitizing acoustic DAT recordings at a sampling rate of 40,000Hz with a Kay CSL 4300 (USA). Details of an investigation which examined the relationship between phonetic transcriptions and EPG patterns is reported in Chapter 4.

3.6 Introduction To Subject Details

This section has four main areas:

1. A description of the criteria for subject selection and the rationale behind this.
2. Details of the speech and language assessments that were conducted and why these were chosen.
3. A description of the 10 aphasic subjects, detailing medical and social history plus speech and language abilities immediately post stroke and at the time of recording based on standard assessments.
4. Detailed phonetic descriptions of each subject.

3.7 Criteria For Subject Selection

Selection of appropriate subjects was very specific with a number of requirements being necessary for participation in the project. Firstly, all subjects had to be at least one year post stroke as this was felt to be an adequate time period to ensure neurological stability. They were required to have a diagnosis of mild to moderate aphasia following a left CVA, with relatively good comprehension and syntax. Hearing was to be within normal limits and there was to be no evidence of dysarthria. Following access to medical records it became evident that not all the subjects met these criteria. Whilst speech therapy records reported a left CVA for all patients, the medical notes for some subjects also noted right sided involvement. This information was not available until after the subjects had been selected, a decision based on auditory impressions and speech therapy records. Therefore some subjects did exhibit a mild dysarthria. Since this was not considered to be the major presenting problem and not evident through auditory analysis alone it was decided to include these subjects.

3.8 Assessments

Each patient underwent two standardized clinical assessments prior to EPG recordings:

3.8.1 The Boston Diagnostic Aphasia Examination (BDAE) (Goodglass and Kaplan, 1972)

A general speech and language assessment which looked at all modalities was chosen as this would present an overall picture of the patients' speech and language abilities. The BDAE was selected for the following reasons. Five of the 10 aphasics were participating in another research project and had recently been assessed on the BDAE. Secondly, results from the assessment could be entered into The Computerized Boston (Code, 1989) from which a diagnosis based on classical syndromes could be assigned. Whilst it is recognized that these diagnoses may not be very informative in the light of the recent advances in cognitive neuropsychology, it was felt that the terminology was globally recognized within the field of speech research. That is, terms such as Broca's aphasia and conduction aphasia, for example, produce stereotypical images for those working with acquired aphasia. The Computerized Boston allows for classification by graphically comparing the Rating Scale Profile for a chosen patient with seven standard types (Broca's, Wernicke's, anomic, conduction, transcortical motor, transcortical sensory, and global aphasia). The classical syndrome with the best fit to the individual's profile would be the accepted diagnosis. However, a certain degree of caution is necessary to prevent misdiagnosis. Several of the aphasic's profiles in this study were equally encompassed by two of the standard profiles. Knowledge of the traditional descriptions of these syndromes and of the patients involved was necessary for diagnosis. Often one of the 2 standard profiles was completely unsuitable for the subject in question. Therefore diagnosis was not based on the profile overlay alone but on the descriptions given of the traditional syndromes in the BDAE manual and the patients' presenting features.

The BDAE also awards a severity rating. This is a "scale of capacity for oral communication" (Goodglass and Kaplan, 1972) ranging from zero for patients where no communication is possible, to "5" for patients who have no perceivable handicap. A description of each rating can be found in The Assessment of Aphasia and Related Disorders (Goodglass and Kaplan, 1972: p.26).

3.8.2 The Frenchay Dysarthria Profile (FDP) (Enderby, 1983)

This was administered as a screening tool to eliminate the presence of dysarthria. However, many patients initially considered not to be dysarthric demonstrated scores which would usually be associated with the disorder. There seemed to be two reasons for this discrepancy. Firstly, it is felt that the FDP is not sensitive enough to distinguish between apraxia and dysarthria. Whilst normative data is reported in the manual (Enderby, 1983) for both normal adults and dysarthric patients with confirmed medical diagnoses, it seems that the assessment was not tested on subjects diagnosed with AOS. Secondly, it appeared that whilst dysarthria was not considered the major presenting feature on auditory analysis for any subject, on assessment some demonstrated a mild dysarthria of one or more of the articulatory organs of speech. It was decided that since this was not the major presenting symptom and that from auditory analysis alone this had not been diagnosed, then those subjects with a mild dysarthria revealed through administration of the FDP would be included in the study. Differential diagnosis of AOS and dysarthria was based on discrepancies between voluntary versus involuntary movements using the speech musculature, clinical reports, and whether the subject had any difficulties with chewing and swallowing. Problems related to involuntary movements and mastication were taken to be evidence for the presence of a dysarthria.

3.8.3 Western Aphasia Battery (WAB) (Kertesz, 1982)

Some patients had also recently been assessed using the WAB due to involvement in therapy and other research. Where this is the case Aphasia Quotient (AQ) will be given (see Table 3-10). The AQ is a summary score indicating the severity of language impairment. The arbitrary cut-off has been set at 93.8. A patient achieving an AQ of greater than 93.8 is not considered to have aphasic impairment.

3.9 Description Of Subjects

The 10 subjects with acquired aphasia will now be considered individually in more detail. As much information as possible has been gathered from medical and speech and language therapy charts with additional information from the clients themselves and their caregivers. Summaries of background history are given in Table 3-9. For each subject the picture description of the Cookie Theft is given in Appendix A. A brief summary of their performance on the BDAE and the FDP is given in this section. No dysarthria assessment was carried out on subject BA who participated in the pilot study. The decision to screen all subjects with the FDP was made following access to the medical records which revealed the presence of right sided involvement of the cerebral cortex for several subjects. At this point it was felt that post examination of BA would be invalid. Further details from the auditory comprehension, oral expression, understanding written language and the writing sections of the BDAE are given in Appendix A along with profiles from the BDAE and the FDP. Where possible CT scans have been obtained (Appendix A). However, since many of the subjects are several years post stroke many had been destroyed and for one subject no CT scan was performed.

Subject	Age (yrs: mos.)	Months post CVA	Medical aetiology	Concomitant difficulties
FM	51:06	83	Left middle cerebral artery infarct	Dense right sided hemiparesis
MU	58:03	144	Multiple infarcts in left middle cerebral artery	None
BA	51:09	110	Left cerebral infarct secondary to internal carotid artery occlusion	Dense right sided hemiparesis
CR	48:01	35	Small area of low attenuation in the left parietal region anteriorly within the basal ganglia impinging on the lentiform nucleus. Also small area of low attenuation in the region of the right caudate nucleus at the anterior limb of the internal capsule	Mild right sided hemiparesis affecting mainly upper limb
JM	50:10	29	Large infarct of the left fronto-parietal lobe	Dense right sided hemiparesis
IE	63:07	49	Large infarct without haemorrhage in the region of the left basal ganglia	Dense right sided hemiparesis
PW	64:07	17	Left middle cerebral artery infarct	Dense right sided hemiparesis
FC	69:11	23	Left middle cerebral artery infarct, no haemorrhage, at the junction with the frontal and parietal lobe with previous lacuna infarcts centred on the left basal ganglia. Two previous CVA's possibly right sided	Dense right sided hemiparesis
HJ	75:02	72	Left cerebro vascular accident (no details available)	Very mild right sided hemiparesis
HL	68:00	45	Left frontal lobe infarct anterior to motor cortex and central sulcus, established right frontal infarct	Resolved hemiplegia

Table 3-9: Background history (medical aetiology gathered from CT scans and personal contact with neurologists).

Subject	Date of Recording	Boston Diagnostic Aphasia Examination			Western Aphasia Battery		Auditory Impression
		Date	Severity rating	Classification	Date	Aphasia Quotient	
FM	September 1995	September 1995	1	Broca's aphasic with AOS	July 1995	84.4	Non-fluent, single words, short phrases and automatisms Word finding difficulties Motoric difficulties
MU	March 1995	December 1994	1	Broca's aphasic with AOS	January 1995	56.4	Very non-fluent, mainly single words, some automatisms Groping evident, aware of errors
BA	May 1994	November 1993	4	Broca's aphasic	December 1993	70.2	Non-fluent, often telegrammatic, content words, few prepositional sentences Mild literal paraphasia
CR	May 1995	March 1994	2	Broca's aphasic	March 1995	81.6	Non-fluent Mainly content words Difficulty with motor coordination
JM	May 1995	December 1993	2	Broca's aphasic	May 1995	85.4	Non-fluent with obvious motoric difficulties Unusual intonational patterns
IE	April 1995	November 1993	2	conduction aphasic	Not tested		Non-fluent, telegrammatic speech Word finding difficulties Persistent t/k substitutions
PW	October 1995	September 1995	2	conduction aphasic	Not tested		Non-fluent with word finding difficulties Frequent phonemic paraphasic errors
FC	October 1995	March 1996	4	anomic aphasic	November 1993	79.6	Mildly non-fluent speech Slow rate, word finding difficulties
HJ	October 1995	October 1995	5	anomic aphasic	March 1995	93	Articulatory problems - possible mild dyspraxia and dysarthria Mild word finding difficulties
HL	March 1995	December 1993	4	anomic aphasic	June 1993	75.4	Hesitant speech with mild word finding difficulties Occasional literal paraphasia

Table 3-10: Summary of aphasia assessments.

3.9.1 FM

This 51 year old gentleman lives at home with his wife, and has two grown up children living away from home. He suffered a left middle cerebral artery infarct in October 1988. The CT scan performed post CVA was considered "too early to show infarct". FM's medical history is varied. There are complaints of chest pains in 1971, choking attacks in 1979, dizziness and a general feeling of unwell felt to be cardio vascular in origin in 1981. There is also mention of a head injury but details are not given and the limited information available is contradictory with regards to the timing of this (at age 18 or 39 years). His CVA has left him with a marked hemiparesis. He walks short distances with the aid of a stick. He received regular speech and language therapy until 1992. Since then he has attended a local stroke club where social interaction is the emphasis. Details of the BDAE and FDP can be found in Appendix A. A summary of these follows.

3.9.1.1 Boston Diagnostic Aphasia Examination

FM presents as a Broca's aphasic with AOS. His auditory comprehension is good with scores above the 80th percentile His expressive language is typically non-fluent consisting of single words, short phrases, filled pause, automatisms and he demonstrates moderate word finding difficulties. His speech is greatly hindered by impaired articulatory abilities and he often uses gesture to assist his communication. A severity rating 1 was awarded. Details of all sections of the BDAE can be found in Appendix A.

3.9.1.2 Frenchay Dysarthria Profile

Impairment was noted throughout this assessment. However, it was felt that this assessment did not differentially diagnose dysarthria and AOS. Since FM does not show consistent impairment during involuntary activities the difficulties recorded were felt to be apraxic in origin. Furthermore, he demonstrates normal function during some subtests for a particular articulatory organ but impairment during others (for example, Lips: FM scored "a", normal function, for "at rest", "spread", and "seal" yet had difficulty with coordinating two movements involving the lips).

3.9.2 MU

This gentleman, aged 58 years, suffered a left CVA in March 1983. Separated from his wife and with two grown up sons, he now lives in sheltered housing accommodation. Contact with other people is limited. Prior to his stroke he had an office based job within the civil service.

MU had been treated for hypertension but had stopped taking the medication approximately 9 months prior to his CVA. He is also reported to have been a heavy drinker. Initial investigations revealed an enlarged heart and pulmonary oedema. An electrocardiogram (ECG) confirmed left ventricular hypertrophy. A CT scan showed a large infarct affecting practically the whole of the left side of the brain. An echocardiogram was very suggestive of a congestive cardio myopathy. Little detail is known of his initial speech and language difficulties due to the length of time post onset (144 months). However, one consultant described him as "totally dysphasic".

Speech and language therapy notes obtained from June 1984 (15 months post onset) state that MU demonstrated characteristics of aphasia with sensory motor involvement (Schuell, 1973). MU received therapy until March 1992 when it was felt that his speech and language skills had reached a plateau.

Assessment results prior to recording are summarized below. For more details the reader is directed to Appendix A.

3.9.2.1 Boston Diagnostic Aphasia Examination

MU presents as an extremely non-fluent aphasic. On the Computerized Boston (Code, 1989) MU is classified as a Broca's aphasic and awarded a severity rating score 1. He has obvious articulatory difficulties typical of AOS without oral apraxia. His spontaneous speech is limited to single words and automatisms. He demonstrates frequent groping and repetition and is very aware of his difficulties. However, his auditory comprehension appears relatively intact. Details of the other sections of the BDAE can be found in Appendix A.

3.9.2.2 Frenchay Dysarthria Profile

MU scored within normal limits for most tasks on the Frenchay Dysarthria Profile. Of note was a considerable jaw deviation when asked to spread his lips, and a slight asymmetry on alternating "oo-ee" and occasional involuntary twitching movements of the tongue at rest. Intelligibility was greatly reduced. No single words and only four sentences were correctly identified by the examiner. However, with consideration to MU's performance on the rest of the profile, the reduced intelligibility is not felt to be due to dysarthria.

3.9.3 BA

A 52 year old gentleman, previously fit and healthy, who suffered a left cerebrovascular accident in March 1985 resulting from total occlusion of the left middle cerebral artery. He lives at home with his wife and has two grown up children. Prior to his stroke he worked as an actuary in a large insurance company after obtaining a first class honours degree. In his spare time he is a keen musician. Immediately after and for some time post stroke, BA suffered from depression which was aggravated by the onset of seizures. These are now successfully controlled through medication.

A neurological examination immediately post stroke identified a reduction in sensation in the right trigeminal area and a right sided hemiparesis. A CT scan 9 months post CVA revealed a low density area and shrinkage in the left middle cerebral artery territory and a slight ipsolateral hydrocephalus. The conclusion from the scan was that BA had suffered a left cerebral infarct secondary to an internal carotid artery occlusion.

Immediately post stroke BA was diagnosed as globally aphasic. Initially he received intensive daily therapy as an in-patient. On discharge from hospital speech and language therapy continued on a weekly individual basis until January 1994, with group therapy continuing until June 1994. He has made significant gains in therapy and is currently considered to be a Broca's aphasic with word finding difficulties. A summary of the BDAE and the FDP are given below. For further details of assessments see Appendix A.

3.9.3.1 Boston Diagnostic Aphasia Examination

BA answered questions appropriately and was able to hold a conversation at a simple level or when the context was well defined. However, when language becomes relatively complex, deficits in receptive abilities emerge. He presents as a non-fluent aphasic, his expressive speech consisting of mainly content words. He experiences lexical retrieval problems adding to the non-fluency and exhibits mild phonemic paraphasic errors which are more common when reading aloud than during spontaneous speech. This suggests impairment at the phonological output lexicon. Communication is assisted by the spontaneous use of gestures and drawing. An example of his expressive speech during picture description can be found in Appendix A.

BA was awarded a severity rating of 4 on the BDAE which indicates "Some obvious loss of fluency in speech or facility of comprehension, without significant limitation on ideas expressed or form of expression" (Goodglass and Kaplan, 1972: p.26). The Computerized Boston (Code, 1989) suggested that a diagnosis of Broca's aphasic with word finding deficits best fits the test scores.

3.9.4 CR

This gentleman suffered 2 left CVAs (with accompanying damage to the right side during the first) within the space of 3 months at the age of 45. He lives at home with his wife. Previously hypertensive, CR had extensive vascular disease including right renal artery stenosis and right superficial femoral artery occlusion requiring intervention. Prior to his second stroke he was awaiting investigation for possible carotid artery surgery. A CT scan, 3 days after his first stroke in June 1992 indicated a small area of low attenuation in the left parietal region anteriorly within the basal ganglia and impinging on the lentiform nucleus (Figure 4, Appendix A, specifically plate 5). Another small area of low attenuation was present in the region of the right caudate nucleus at the anterior limb of the internal capsule. The appearance was that of an established infarct. Medical investigation following his second CVA in September 1992 revealed a right upper motor neurone weakness and decreased tone in the right upper limb. Cardiac ultrasound showed occlusion of the left internal carotid artery and a 50 to 60% stenosis of the right internal carotid artery. The consultant's records highlight the fact that patients with a very severe vascular pathology can sometimes be supplying the whole brain through one cranial vessel. A small drop in blood pressure, for example on standing, can be a very potent cause of cerebral ischaemia. In this case it was felt that the ischaemic attack was probably in the brain stem.

Initially post stroke, CR presented as a global aphasic. He received regular therapy until February 1993. He then attended a college specializing in training opportunities for people with disabilities where he was then referred for more speech and language therapy. He currently attends a weekly aphasic group for speech and language therapy. A summary of his performance on the BDAE and FDP is given below. For further details of assessments see Appendix A.

3.9.4.1 Boston Diagnostic Aphasia Examination

CR answered questions appropriately mainly using "yes" and "no" responses and single words. His auditory comprehension skills are relatively unimpaired. Expressively, he presents with non-fluent speech which consists mainly of two and three word phrases. There are many filled and unfilled pauses and evidence of word finding difficulties. CR experiences particular difficulty with sequencing and coordinating motor movements and displays groping movements. He achieved a severity rating 2 and was classified as a Broca's aphasic on the Computerized Boston (Code, 1989). Details of the assessment can be found in Appendix A.

3.9.4.2 Frenchay Dysarthria Profile

CR only experienced mild difficulties with alternating tongue movements. Intelligibility is reduced for both words and sentences but is not felt to be a result of any dysarthric impairment.

3.9.5 JM

A 50 year old gentleman, previously active and well, who suffered a left CVA in December 1992 resulting in a right hemiplegia and dysphasia. A CT scan in December 1992 revealed a large infarction of the left fronto parietal lobe (Figure 6, Appendix A). This had destroyed the left anterior cerebral artery and possibly the middle cerebral artery. Investigation on admission into hospital revealed a mild right sided facial weakness and a right hemianopia, right hemiparesis and apraxia.

On initial assessment of speech and language, comprehension was limited to matching and following simple commands. His expressive abilities were marred by word finding difficulties and what was described by the speech and language therapist as a "phonological dyspraxia". Particular difficulty was noted for those phonemes requiring tongue elevation.

JM has received regular individual therapy since the time of his stroke. He now also attends an aphasic stroke group on a weekly basis. A summary of his performance on the BDAE and the FDP is given below. For further details see Appendix A.

3.9.5.1 Boston Diagnostic Aphasia Examination

JM is able to follow conversation although sometimes it is necessary to repeat or clarify questions. He is a non-fluent aphasic, whose spontaneous output consists mainly of content words, a maximum of 3 or 4. Speech is often assisted by gesture or writing His articulation is often distorted and he has obvious difficulties in sequencing and coordinating speech sounds. Sound substitutions are frequent and his speaking rate is reduced. He has unusual intonational patterns which are similar to those of a deaf speaker. He scored a severity rating of 2 which is characteristic of the pressures placed on the listener when engaged in conversation with JM. At the present time he is classified as a Broca's aphasic. Details of the other subtests from the BDAE are summarized in Appendix A.

3.9.5.2 Frenchay Dysarthria Profile

JM was able to perform all the motoric movements easily with the exception of alternating tongue patterns. His articulation was slow and he was unable to move with ease from /kɑ/ to /lɑ/, perseverating on one sound.

Although intelligibility is greatly reduced in words, sentences and conversation, this is not felt to be a result of a general impairment to the speech musculature.

3.9.6 IE

A 63 year old gentleman who suffered a left CVA in March 1991 whilst ski-ing. An officer in the army, he lived with his wife who has since died, and he has two grown up sons. He now lives with a housekeeper and leads a very full and active life, working and travelling. Previously thought to be fit and healthy, a Dopplers investigation, which uses sound waves to reveal arterial movement, indicated no flow in the left carotid artery. The remaining vessels appeared clear with no significant atheroma. The reason for the thrombosis is unclear, although possible local disease in the carotid syphon and retrograde thrombosis was suggested. A CT scan performed one month post stroke showed a large infarct without haemorrhage in the region of the left basal ganglia (Figure 8, Appendix A). This has destroyed the whole of the lentiform nucleus and internal capsule. The basal cisterns and ventricular systems are of normal size and configuration. The appearances suggested a large acute left temporo-parietal infarct.

A neurological examination immediately post CVA showed decreased tone on the right side affecting both upper and lower limbs. A mild right sided upper motor neurone facial weakness was also noted.

On initial assessment of speech and language skills, IE presented with a mixed dysphasia with dyspraxia and a dense right sided hemiplegia. At this time he was able to understand single lexical items but unable to follow instructions. There was no functional language, his output consisting of paraphasia, perseveration and jargon. He was also unable to join in serial speech or respond to any cueing. In addition, he was extremely emotionally labile.

IE has received regular individual therapy since the time of his stroke. He still attends weekly group therapy and has made significant gains. Results of the assessments are summarized below.

3.9.6.1 Boston Diagnostic Aphasia Examination

IE is a very social gentleman who is eager to communicate. He presents with mild auditory comprehension difficulties and non-fluent aphasia. His spontaneous speech is repetitive and frequently lacks reference resulting in confusion during longer utterances. He experiences moderate word finding difficulties and his verbal output is characterized by frequent literal paraphasic errors. He was classified as a conduction aphasic from The Computerized Boston (Code, 1989). A severity rating of 2 was awarded to IE which suggests that communication is possible but with assistance from the conversational partner. Details of the other subtests can be found in Appendix A.

3.9.6.2 Frenchay Dysarthria Profile

A very slight asymmetry when asked to spread his lips and mild tongue elevation difficulties were noted on conduction of this profile. Intelligibility was reduced for words (7/10 correctly identified) and unsurprisingly more severely impaired for sentences (5/10 correctly identified). However, at the conversation level intelligibility was only mildly reduced (rated "b"). IE is not considered to be dysarthric.

3.9.7 PW

This 64 year old lady lives at home with her husband. She has 2 children, both married and living away from home. Her CVA in May 1994 was preceded by a left carotid territory trans ischaemic attack (TIA) in April of the same year. On admission into hospital following her stroke, a CT scan showed extensive low density within the left middle cerebral artery territory with moderate mass effect but no midline shift and no evidence of haemorrhage. The conclusion was a recent left middle cerebral artery infarction. Neurological examination revealed a right sided upper motor neurone palsy with increased tone on the right side of the body.

PW received regular individual therapy in a rehabilitation unit. On discharge she was hesitant to attend an aphasic group for further therapy. According to the Speech and Language Therapist she presented with a "very mild receptive dysphasia and a moderate expressive dysphasia plus a phonological dyspraxia". Assessment results prior to recordings are summarized as follows. For further details see Appendix A.

3.9.7.1 Boston Diagnostic Aphasia Examination

PW responded to questions appropriately. She presents as a non-fluent aphasic with moderate word finding difficulties, frequent phonemic paraphasic errors and many filled and unfilled pauses. PW scored a severity rating of 2 which suggests that conversation on familiar topics is possible although there are often frequent breakdowns in the interaction.. Her classification is conduction aphasia. Details of the other sections from the BDAE are given in Appendix A.

3.9.7.2 Frenchay Dysarthria Profile

PW demonstrated slight asymmetry and mild difficulties during alternating tongue movements. Intelligibility was only very mildly reduced in conversation. Words and sentences were 100% intelligible.

3.9.8 FC

This gentleman suffered a CVA in November 1993. He lives at home with his wife and has two grown up children. FC had 2 previous strokes but he reports that only the third produced any lasting effect on his speech and language. There appears to be some confusion in the medical notes as to the location of the first two CVA's. It is unclear if they were both right sided CVA's or whether it was only the first that involved the right hemisphere. However, a CT scan following his third stroke identified a recent left middle cerebral artery territory infarct with no haemorrhage (Figure 11, Appendix A). Damage was also seen at the junction with the frontal and parietal lobe, not felt to be extending as high as the motor cortex (plate 7, Figure 11, Appendix A). Previous lacuna infarcts centered on the left basal ganglia can also be identified. He sustained a right upper motor neurone facial weakness with deviation of the tongue to the right side and a flaccid weakness of the right side, the upper limb being more severely affected than the left. His mobility is poor such that he uses a wheelchair.

Initially he was considered to be a non-fluent dysphasic with accompanying dyspraxia, dysarthria and dysphagia. However, he retained good comprehension. He was, and continues to be, emotionally labile. On discharge from the hospital he was conversing in sentences which, according to his speech and language therapist, were "quite fluent if he was relaxed but slow and hesitant if he felt under pressure". A summary of the assessment results is given below.

3.9.8.1 Boston Diagnostic Aphasia Examination

FC presents with good receptive and expressive skills. His verbal output is slow and stilted with mild word finding difficulties and literal paraphasic errors. Articulation is often imprecise, there is repetition and prolongation of initial sounds. He was given an aphasia severity rating of 4 indicating some obvious loss of fluency. He is classified as mildly anomic. Details of the subtests can be found in Appendix A.

3.9.8.2 Frenchay Dysarthria Profile

Most of the scores fell below the levels considered to be indicative of normal functioning, a feature which is not surprising in view of the bilateral cerebral damage. Generally, FC scored higher for specific articulators "in speech" than during isolated movements. Greatest impairment involved the lips and tongue. Asymmetry was noted for all lip behaviours and rates were decreased. Tongue movements were also slow, imprecise and perseveration was evident. Earlier medical investigation revealed a right upper motor neurone weakness which would be consistent with the dysarthric involvement identified. However, the good intelligibility during conversation is not in accordance with this diagnosis.

3.9.9 HJ

This 75 year old lady is single and lives alone although she has regular contact with her brother and his family. Both prior to and post stroke, she is a very active woman. She used to be a secretary and has also worked in a shop. At the time of her CVA she was retired. She was admitted to hospital in September 1989 following a left CVA. Access to medical notes was not possible for this lady. All information was gathered from Speech and Language therapy case notes. She has a previous medical history of hypertension and a bilateral cataract which was operated on 5 weeks prior to her stroke. Examination following her CVA indicated a right hemiplegia, right facial weakness with tongue deviation to the right, and dysphasia. Her speech and language therapy case notes state that following assessment she was classified as being severely dysphasic initially, but resolving to a mixed dysphasia with moderate dyspraxia of speech and a mild upper motor neurone dysarthria. She was discharged home in November 1989 and subsequently attended group therapy for a short period. She no longer receives any speech and language therapy but attends a local stroke club on a weekly basis. A summary of assessment results follow.

3.9.9.1 Boston Diagnostic Aphasia Examination

HJ demonstrates excellent comprehension, both auditory and reading. Her expressive spoken language is characteristically full, complex sentences. (See "Cookie Theft", Appendix A). She has mild lexical retrieval problems, occasional phonemic paraphasia, and articulation best described as imprecise. Self monitoring of intelligibility is poor resulting in listener difficulties. HJ wears upper and lower dentures which appear ill-fitting and are possibly contributing to impaired intelligibility. She was considered to have a severity rating of 5. According to Goodglass and Kaplan (1972) this represents "minimal discernible speech handicaps; patient may have subjective difficulties that are not apparent to the listener" (p.26). HJ was classified as mildly anomic. Further details of the BDAE are given in Appendix A.

Administration of the WAB was in agreement with the above. HJ achieved an Aphasia Quotient (AQ) of 93 suggesting a very mild aphasic impairment.

3.9.9.2 Frenchay Dysarthria Profile

Results from the FDP screen suggest a mild dysarthria. Greatest difficulty was with lateral and alternating tongue movements where HJ scored a "C". Intelligibility was poorer for single words (8/10) than the sentences which were rated as normal. However, ill-fitting dentures may have affected the scoring since lower dentures were displaced during tongue activity.

3.9.10 HL

This gentleman lives at home with his wife, his 2 children having left home and with families of their own. He suffered a left CVA in April 1991 at the age of 68. This was preceded by an episode of slurred speech and left sided facial weakness in March 1990. In March 1991 he experienced weakness in his left arm lasting approximately 15 minutes. Therefore there appears to have been bilateral cerebral damage. HL has a known history of ischaemic heart disease and angina and was diagnosed as hypertensive in 1983.

On admission into hospital in April 1991, he presented with right sided neglect and a mild right sided facial weakness, hyper reflex in the right leg and a right homonymous hemianopia and conjugate deviation to the left. A CT scan in April 1991 identified a recent infarct within the left frontal lobe anterior to the motor cortex and central sulcus. A well established right frontal infarct could also be seen (Figure 14, Appendix A, specifically plates 6 to 9).

Speech therapy records state that initially HL presented with a severe expressive dysphasia, moderate receptive difficulties and dyspraxia. Comprehension and word finding difficulties improved quite quickly, the dyspraxia more gradually. HL has received regular therapy since his CVA, initially individually, but he now attends weekly group therapy. A summary of the assessment results follow.

3.9.10.1 Boston Diagnostic Aphasia Examination

During section 1 of the BDAE (Conversational and expository speech) HL answered all questions appropriately, usually in full sentences. Speech was occasionally hesitant and characteristically slow. Sentences were linked together and ideas followed on from one another. Occasionally HL selected the wrong pronoun or word, and omitted morphological endings, for example plurals. All of these can be seen in the example of his spontaneous speech (see Appendix A). He therefore presents as a fluent aphasic with minimal word finding difficulties and occasional literal paraphasic errors. Whilst the Computerized Boston classifies him as an anomic aphasic, it is felt that this diagnosis is a little misleading since his problems are very mild and could easily be attributed to normal ageing processes. The examiner awarded a severity rating 4. Further details of the BDAE can be found in Appendix A. On administration of the WAB in June 1993 he achieved an AQ of 75.4.

3.9.10.2 Frenchay Dysarthria Profile

HL is not considered to have any residual dysarthria. He had difficulty increasing his volume during counting and some problems with tongue elevation. However, these were isolated errors. Whilst intelligibility of words and sentences were reduced this was not true of conversation. This was felt to be a result of the design of the profile, since intelligibility of words and sentences is based on the subject's ability to read. The examiner feels that HL misread the words which resulted in a lower score. Intelligibility in conversation is 100%.

3.9.11 Control speakers

Ten speakers, four male and six female, with no history of speech and language or hearing problems were chosen for control purposes. All were native speakers of English (seven English, two Scottish, one Australian). The control speakers were aged between 25 years and 65 years.

3.9.12 Phonetic description

Broad phonetic transcriptions from each subject were made from Word lists A and B and the repetition task. These can be found in Appendix A. The main phonetic characteristics for each subject are summarized in Table 3-12. Examples of processes are given, for example, substitution, and the number of distinctive features typically involved in the error are noted. Distinctive features are seen here as part of the definition of phonemes where the term refers to "a minimal contrastive UNIT recognized by some linguists as a means of explaining how the sound SYSTEM of languages is organized" (Crystal 1991: p.109). Phonetic symbols are taken from The International Phonetic Alphabet revised to 1993. Less familiar symbols are listed in Table 3-11:

Symbol	Key
s̠	retracted
(.)	syllable break
k̙	retracted tongue root
ʎ	palatal lateral approximant
ʃ̬	voicing
k̬	final partial voicing
d̥	devoicing
d̥	final partial devoicing
ĕ	extra short

Table 3-11: Less familiar phonetic symbols used in the transcriptions taken from The International Phonetic Alphabet (1993 revision).

Subject	Classification	Phonetic description
FM	Broca's with AOS	Errors typically involved 1 or 2 distinctive features. Substitution (e.g. "gear" → [diɹ] "key" → [di:]) Voicing errors (e.g. "tick" → [ɟɪk]) Overshoot of fricatives (e.g. "shark" → [tʃaɹp]) Undershoot for affricates (e.g. "cheer" → [ʃiɹ] Phoneme addition (e.g. "catkin" → [skat'k̬ɪn]) Cluster reduction (e.g. "squashkit" → [sw:ɔskɪt]) Sequencing difficulties (e.g. "catkin" → [tkat'kɪn] "skirt" → [xskɜ:t]) Prolongation of phonemes in particular vowels
MU	Broca's with AOS	For monosyllabic words errors typically involved 1 distinctive feature. Substitution alveolar/velar and velar/alveolar (e.g. "key" → [tʰi]) Substitution of bilabial fricatives for bilabial plosives (e.g. "box" → [ɸɔts]) Overshoot (e.g. "shark" → [tʃaɹt]) Devoicing (e.g. "zoo" → [su] "book" → [put]) Assimilation (e.g. "beak" → [ɸ/pi:pt]) Disyllabic words showed unsystematic errors, groping of articulators and frequent perseveration Perseveration: see Word list B repetition 2 (Appendix A) compare "tickling" → [kɹɪkɯɪn] and "deckchair" → [ɯɪkɯɪn]) Groping but syllabic structure is preserved: (e.g. "bookshop" → [ɸuts.tkɹɔt] "witchcraft" → [ɹɪtsɯfads]) Incorrect production of target vowels (e.g. "catkin" → [kʰʌtgɪʤs]) Productions are typically hesitant and weak
BA	Broca's aphasic (without AOS)	All errors involved one distinctive feature. Substitution: affecting place of articulation, affected words with more complex phonemic structure (e.g. "cocktail" → [tʰɔt'tel]) Devoicing: in all positions of plosives and fricatives (e.g. "zoo" → [z̥u]) Sequencing errors: Metathesis (e.g. "cocktail" → [kʰɔtʰkel]) Syllable breaks (e.g. "headlight" → [hɛd.(..) laɪt])
CR	Broca's aphasic (without AOS)	Most errors involved either 1 or 2 distinctive features. Substitution: affecting place and manner of articulation (e.g. "key" → [tʃi] "shark" → [fɸaɹk]) Denasalization: (e.g. "mouse" → [b^{n}aus]) Assimilation: (e.g. "fish" → [ʃ:ɓɪʃ]) Errors involving clusters: reduction and often associated error of placement (e.g. "skirt" → [ʃɜɹt], "squashkit" → [gwɔskɪt]) Particular difficulty with manner of articulation: (e.g. "tickling" → [ɸɪkəlɪŋ], "weekday" → [bɪk'be])
JM	Broca's aphasic (without AOS)	Errors typically involved simplification processes Cluster reduction (e.g. "clock" → [qɔ̃k] "star" → [sa:]) Assimilation (e.g. "weekday" → [wi:kge] "catkin" → [katdɪ̃n]) Velopharngeal insufficiency was also evident affecting both vowels and consonants (e.g. "kitkat" → [kʰɪ̃dnat])
IE	conduction aphasic	Errors characteristically involved 1 distinctive feature. Substitutions frequently involving alveolar/velar and velar/alveolar in word initial and word final position (e.g. "key" → [tʰi] "book" → [buʌt]) Overshoot of /s/ and /ʃ/ (e.g. "shark" → [t͡tʃɑ:t]) Substitution of /s/ for /ʃ/ (e.g. "she" → [si:] "fish" → [fɪs]) Sequencing errors (e.g. "tick" → [kʰɪt] "cocktail" → [kʰɔkt͡keɪl] "kitkat" → [tʰɪk'tækt]) Assimilation (e.g. "tickling" → [tʰɪtəlɪn])

Subject	Classification	Phonetic description
PW	conduction aphasic	Errors typically involved 1 distinctive feature but errors are frequently self corrected. Substitution alveolar/velar (e.g. "key" → [ə tʰi ə kʰi]) Repetition of single phonemes (e.g. "sea" [ð: s: z: si ðə di]) Syllable breaks (e.g. "kitkat" → [kɪt.kat] "headlight" → [hɛd.laɪt] "weekday" → [wi:k.de])
FC	anomic	Errors were infrequent and typically involved 1 distinctive feature. Voicing errors particularly in more complex sequences (e.g. "kitkat" → [k̬ɪt'gat] "squashkit" → [s:gwɔʃgɪt]) Assimilation usually self corrected (e.g. "seed" → [si:z sid]) Substitution usually self corrected (e.g. "gear" → [ɔ ɖ ɔ giɹ]) Sequencing difficulties: Phoneme addition (e.g. "clock" → [k̬əlɔk]) Syllable break (e.g. "deckchair" → [dɛk.tʃɜɹ])
HJ	anomic	Mild difficulties involving placement Frequent overshoot of alveolar fricatives (e.g. "sea" → [sti] "sun" → [t͡sʌn] "seed" → [stid] "shop" → [tʃɔp]) Placement errors for velar plosives involving 1 distinctive feature (e.g. "kitkat" → [ɢit.kat] "weekday" → [wi:qde]) Sequencing difficulties: Syllable breaks (e.g. "kitkat" → [ɢitʰ.kat]) Phoneme addition (e.g. "clock" → [kʰəlɔk]) Assimilation (occasionally with associated phoneme addition) (e.g. "headlight" → [htɛdɹaɪt]) Assimilation without addition (e.g. "squashkit" → [s:gwɔsgɪt])
HL	anomic	Errors involved syllabic structure and phoneme sequencing. Phoneme and syllable additions (e.g. "beak" → [bəlik] "kitkat" → [kʰɪtikat] "headlight" → [hedəlaɪt]) Syllable breaks (e.g. "weekday" → [wik.de]) Metathesis ("squashkit" → [ks:kwɔʃkɪt])

Table 3-12: Summary of the main phonetic characteristics for all aphasic speakers.

Chapter 4

4. Relationship Between Phonetic Transcription And EPG Patterns

4.1 Introduction

Initial observation of the EPG patterns for the speech items and the phonetic transcriptions indicated that these did not always coincide. This is an important methodological issue which needs further investigating. It was decided therefore to study the relationship in more detail.

4.2 Method

An investigation was carried out to see whether listeners could detect through auditory analysis alone abnormalities in place of articulation which were evident from EPG patterns. One subject, IE, a conduction aphasic who made frequent paraphasic errors, typically alveolar/velar or velar/alveolar substitutions, was chosen. Further details concerning this subject can be found in Section 3.9.6 and Appendix A.

Twenty-four words with target word initial velar or alveolar consonants were chosen from word lists A and B and the repetition task. They were transcribed using narrow phonetic transcription by the author from DAT recordings and the EPG patterns analysed before selection (see Appendix A). There were three groups of 8 words (see Table 4-1):

Group 1	These words displayed normal EPG patterns and were transcribed as the correct target phoneme.
Group 2	The EPG patterns for the word initial consonant were typical, for IE, of the substituted sound. Transcriptions confirmed that the word initial consonant was a substitution (/t/ → [k] /d/ → [g], or /k/ → [t] /g/ → [d]). Therefore the EPG patterns confirmed the perceived substituted phoneme.
Group 3	The EPG pattern showed an abnormal alveolar/velar double articulation where the target was either a single alveolar or velar. They were transcribed as either a correct production or as a substitution.

Table 4-1: Description of the words chosen for the perceptual study and their subdivision into groups.

The words with their phonetic transcription and corresponding EPG description can be seen in Table 4-2.

	Target word	Phonetic transcription	WI EPG pattern
1.	tick 1	[kʰɪt]	k
2.	kitkat 5	[tʰɪtkæt]	t
3.	kitkat 6	[tʰɪdkæt]	double articulation
4.	kitkat 7	[tʰɪtkæt]	double articulation
5.	tear 1	[tʰiə]	t
6.	kitkat 1	[tʰɪdkæt]	t
7.	tip 1	[tʰɪp]	t
8.	catkin 2	[kʰætkɪn]	k
9.	deer 4	[di:ə]	double articulation
10.	kitkat 8	[kʰætʰʊt]	double articulation
11.	car 1	[kʰa:ɹ]	k
12.	key 2	[tʰi:]	double articulation
13.	kitkat 2	[tʰɪdkæt]	t
14.	gear 1	[di:əɹ]	d
15.	kitkat 3	[tʰɪtkæt]	t
16.	deer 1	[di:əɹ]	d
17.	car 2	[kʰa:ɹz]	double articulation
18.	cocktail 1	[kʰɒkteɪl]	k
19.	tip 2	[tʰɪp]	t
20.	dart 2	[da:ɹt]	d
21.	tickling 2	[tʰɪtəlm]	double articulation
22.	kitkat 4	[tʰɪtktæt]	t
23.	tick 2	[tʰi:t]	double articulation
24.	key 1	[tʰi:]	t

Table 4-2: Target words with phonetic transcriptions and corresponding EPG description.

The 24 tokens were transferred from DAT onto a Kay CSL at sampling rate 40,000Hz. Using the editing facilities of the Kay, bisyllabic words were spliced after the release of the syllable final consonant leaving a CVC structure. This was designed to help the listener focus on the word initial consonant by eliminating unnecessary distracters. All words treated in this way became a new word (e.g. "catkin" → cat, "cocktail" → cock, "kitkat" → kit, "tickling" → tick). The process of splicing was easy for all words except "tickling" since they all contained an intersyllabic pause readily visible on the acoustic trace. For "tickling" a decision was made based on auditory impression and not the appearance of the waveform. The words were then transferred back onto DAT. Each word was repeated 5 times and randomly ordered. Five additional words were added at the beginning and the end of the tape. These were to help the listeners acclimatise to the task and to avoid recording words that may be accompanied by a loss in concentration. Such a loss in concentration may, for example, occur at the end of the word list. Preceding each word was an announcement in synthesized speech of the number of the word on the tape. There was a pause of three seconds between the end of one word and the start of the announcement.

Sixteen listeners were chosen to rate the recordings. Nine of these were qualified speech and language therapists, the remaining seven were fourth year speech and language therapy honours students who had completed training in phonetics as part of their course. A rating scale based on previous work by Gibbon, Dent, and Hardcastle (1993) and Ingram and Hardcastle (1990) was used to record listener judgments. This requires the listener to indicate where the target sound (syllable initial consonant) fell on a phonetic continuum from alveolar to velar. Each listener was given the following instructions:

You will hear 130 words produced by adults who have a speech disorder. Each word BEGINS with a plosive target and is preceded by either "the" or "a". Please listen carefully to this plosive and indicate on the score sheet its place of articulation.

There are 5 ratings:

If you hear a clear alveolar please circle the number 1 as follows:

Alveolar** 1 2 3 4 5 **Velar

If you hear a clear velar please circle the number 5 as follows:

Alveolar** 1 2 3 4 5 **Velar

There are 3 ratings between these two points.

A 3 indicates that the sound could not be identified as either alveolar or velar but at a point midway between the two.

A 2 indicates that the sound you perceived was more alveolar than velar but not as clear as a rating of 1.

A 4 indicates that the sound you perceived was more velar than alveolar but not as clear as a rating of 5.

You will hear the tape only ONCE. Please do not pause or rewind the tape. Should you be unsure about any sound please make a guess and listen carefully to the next word.

Each listener was placed in a sound damped studio and instructed to start the tape when they were ready.

4.3 Results

4.3.1 Intra-subject reliability

Individual listener ratings for each of the five repetitions of each word were accumulated and compared. It was decided that any listener who deviated by three or more ratings for the five repetitions on five or more words was unreliable and was eliminated from the investigation. For example, if an individual awarded ratings similar to those below (target word "deer") for more than 5 identical words, their score sheet was ignored.

Alveolar** 1 2 3 4 5 **Velar

Alveolar** 1 2 3 4 5 **Velar

Alveolar** 1 2 3 4 5 **Velar

Alveolar** 1 2 3 4 5 **Velar

Alveolar** 1 2 3 4 5 **Velar

Two out of the sixteen listeners were felt to be unreliable. One made judgments on eight words that were 3 or more ratings apart and the other was inconsistent on 6 of the twenty-four words. The ratings for each word were then totaled. The actual figures are shown in Table 4-3. There was a total of 70 ratings for each word (14 subjects × 5 repetitions of each word). Results are displayed graphically with corresponding EPG patterns in Figure 4-1, Figure 4-4 and Figure 4-10. There are five EPG reference points for each word (see Table 4-4).

Target Word	Ratings					Total
	1	2	3	4	5	
tip 1	21	11	13	19	7	70
catkin 2	0	3	5	27	35	70
car 1	0	0	0	0	70	70
deer 1	60	10	0	0	0	70
cocktail 1	0	5	1	33	31	70
tip 2	51	18	1	0	0	70
dart 2	36	22	6	5	1	70
tear 1	37	17	6	7	3	70
tick 1	3	3	2	26	36	70
kitkat 1	17	16	12	20	5	70
kitkat 2	27	24	14	5	0	70
kitkat 3	32	18	16	2	2	70
gear 1	54	16	0	0	0	70
kitkat 4	4	22	21	21	2	70
key 1	66	3	1	0	0	70
kitkat 5	22	35	10	3	0	70
kitkat 6	14	18	14	22	2	70
kitkat 7	24	28	12	5	1	70
deer 4	38	30	2	0	0	70
kitkat 8	5	4	5	23	33	70
key 2	67	3	0	0	0	70
car 2	0	0	0	4	66	70
tickling 2	2	3	10	30	25	70
tick 2	44	14	10	2	0	70

Table 4-3: Total judgment ratings made by 14 listeners.

EPG reference point	Description	Criteria
1	Approach to closure	Beginning of articulatory constriction for the stop. Taken as the EPG frame where there was evidence of build-up in number of contacts following the previous vowel
2	Closure for the stop	First EPG frame to show complete constriction across the palate
3	Frame of maximum constriction	Frame with most contacts
4	Release of the stop	Last EPG frame to show complete constriction across the palate
5	End of release	From the acoustic trace where regular glottal pulsing following the consonant commences

Table 4-4: EPG reference points relating to Figure 4-1, Figure 4-4 and Figure 4-10.

4.3.2 Inter-subject reliability

A reliability analysis was performed to assess the agreement between the 14 listeners on each individual word over the 5 repetitions. The model chosen was Cronbach's Alpha (Hair, Anderson, Tatham and Black, 1995). For each word a standardized item alpha score was calculated. Scores range from 0 to 1 (negative values are treated as 0). It is generally accepted that standardized alpha scores of 0.7 to 1 signify a strong agreement or reliability between subjects. A score falling between 0.5 and 0.7 indicates moderate agreement, 0.3 to 0.5 indicates a weak agreement and zero signifies no agreement. The results of the reliability analysis are summarized in Table 4-5. The scores suggest that there was strong agreement between listeners over 20 out of 24 words (83% of items). One word from group 1 ("tip" 1) showed no agreement, there was only moderate agreement for two words from group 2 ("kitkat"1 and "kitkat" 4) and one word from group 3 showed weak agreement ("kitkat" 6). These items will be looked at in greater detail in a later section and their corresponding spectrographic displays analysed to try and establish why agreement on these items was poor.

The results will now be considered according to the three groups of words (see Table 4-1) established at the beginning of the perceptual study. Analysis will include the reference EPG frames, graphs showing listener responses, and spectrographic analysis. Table 4-6 summarizes spectral characteristics for alveolar and velar plosives (taken from Kent and Read, 1992 and Harrington and Cassidy, unpublished manuscript).

Word	Standardized alpha item	Agreement
tip 1	0	no agreement
catkin	0.8751	strong
car 1	1.0	strong
deer 1	0.9835	strong
cocktail	0.9040	strong
tip 2	0.9625	strong
dart	0.9181	strong
tear	0.8356	strong
tick 1	0.9219	strong
kitkat 1	0.6173	moderate
kitkat 2	0.7782	strong
kitkat 3	0.8790	strong
gear	0.9765	strong
kitkat 4	0.6962	moderate
key 1	0.9882	strong
kitkat 5	0.8288	strong
kitkat 6	0.4772	weak
kitkat 7	0.7855	strong
deer 4	0.9534	strong
kitkat 8	0.7834	strong
key 2	0.9933	strong
car 2	0.9958	strong
tickling	0.8039	strong
tick 2	0.8527	strong

Table 4-5: Results of the reliability analysis (Cronbach's Alpha)

Standardized Item Alpha scores range from 0 to 1
0.7-1 = strong agreement (reliability) between listeners
0.5-0.7 = moderate agreement
0.3-0.5 = weak agreement
0 = no agreement

Spectral characteristic	Alveolar plosive	Velar plosive
Release Burst	high frequency energy rising spectrum intermediate VOTs	mid frequency energy compact mid frequency spectrum long VOTs
Formant Transitions (Consonant to Vowel)	F1 rising[1] F2 & F3 converging	F1 rising[1] F2 & F3 diverging
Formant Transition (Vowel to Consonant)	F2 & F3 diverging	F2 & F3 converging
F2 locus	1800 Hz	At least 2 F2 loci at 3000 and 1300 Hz
F3 locus	2500-2700 Hz	2200-3000 Hz

Table 4-6: Summary of spectral characteristics for alveolar and velar plosives taken from Kent and Read (1992) and Harrington and Cassidy (unpublished manuscript).

4.3.3 Group 1

This group of 8 words were chosen because on initial analysis of the DAT recordings they were perceived as correctly produced and the corresponding EPG patterns confirmed this decision. Therefore we would expect the listeners to award either a rating of 1 or 5 dependent upon whether the word commenced with an alveolar or velar articulation. Expected values of zero (for the remaining 4 ratings on each word) prevent the application of statistical tests with any degree of confidence. Tests such as Chi squared analysis, which compare observed with expected scores, are inappropriate when the expected values are zero. Therefore the data must be taken at face value.

Figure 4-1 shows the 5 reference EPG points and graphical display of listener judgments for group 1 words. Only one word showed 100% listener agreement. All listeners heard the word initial phoneme in "car" 1 as a velar plosive. The corresponding EPG patterns indicate a velar articulation although full closure is not made. However, this articulation is still regarded as normal for a velar plosive. The open vowel following the word initial velar probably influences the degree of closure as shown on the EPG trace. Full closure may be made beyond the back of the palate and therefore not recorded.

Most of the other items in group 1 showed a tendency for either alveolar or velar ratings with the graphs indicating a skewness towards the correct phoneme. For example, 89% of listeners chose ratings of either 4 or 5 for the word initial consonant in "catkin", and 91% chose these ratings for "cocktail". For word initial alveolar plosives 100% chose a rating of either 1 or 2 for "deer" 1, 99% for "tip" 2, 82% for "dart" 1 and 77% for "tear" 1. One item showed ratings that were almost evenly distributed 1 through 5 with no skewness evident on the graph ("tip" 1). The standardized alpha item for this word was zero indicating no agreement between listeners. Spectrograms were produced for "tip" 1 and "tip" 2 (see Figure 4-2 and Figure 4-3 respectively) to try and determine why "tip" 1 had such poor listener agreement and also why "tip" 2 was more consistently rated. An alveolar plosive is characterized by high frequency energy during the spectral release burst (Kent and Read, 1992). This high frequency energy is not evident from the spectrogram for "tip" 1 (Figure 4-2). Energy is decreasing in the higher frequencies which may explain why a substitution was not heard by the listeners. Furthermore, whilst there is a noticeable convergence of formants 2 and 3 (F2 and F3) leading into the stop which is appropriate for a velar plosive, there is no characteristic divergence following the release of the plosive. Ratings for "tip" 2 favoured 1, 2 and 3 although there were some ratings of 4 and 5. The skew of the graph (Figure 4-1) indicates that more listeners favoured alveolar ratings than

[1]F1 transitions from Consonant to Vowel are less clear for voiceless than voiced consonants. This is because the periodicity starts later and the presence of aspiration prior to voicing onset.

velar. The spectrogram for this item (Figure 4-3) is different to "tip" 1. There is a definite concentration of mid and high energy during the spectral burst which may cause more listeners to detect an alveolar production in preference to a velar. However, F2 and F3 transitions are more typical of a velar stop because they converge leading into the stop and diverge following the release. Therefore the spectral burst is suggestive of an alveolar plosive but the formant transitions indicate a velar articulation. Kent and Read (1992) state that "stop bursts and formant transitions ..... are complementary cues and their integration probably leads to a stronger phonetic percept than would be formed with either one alone" (p.120). It would seem that the listeners in this study, when presented with this conflicting acoustic information, were more influenced by the spectral burst than the formant transitions.

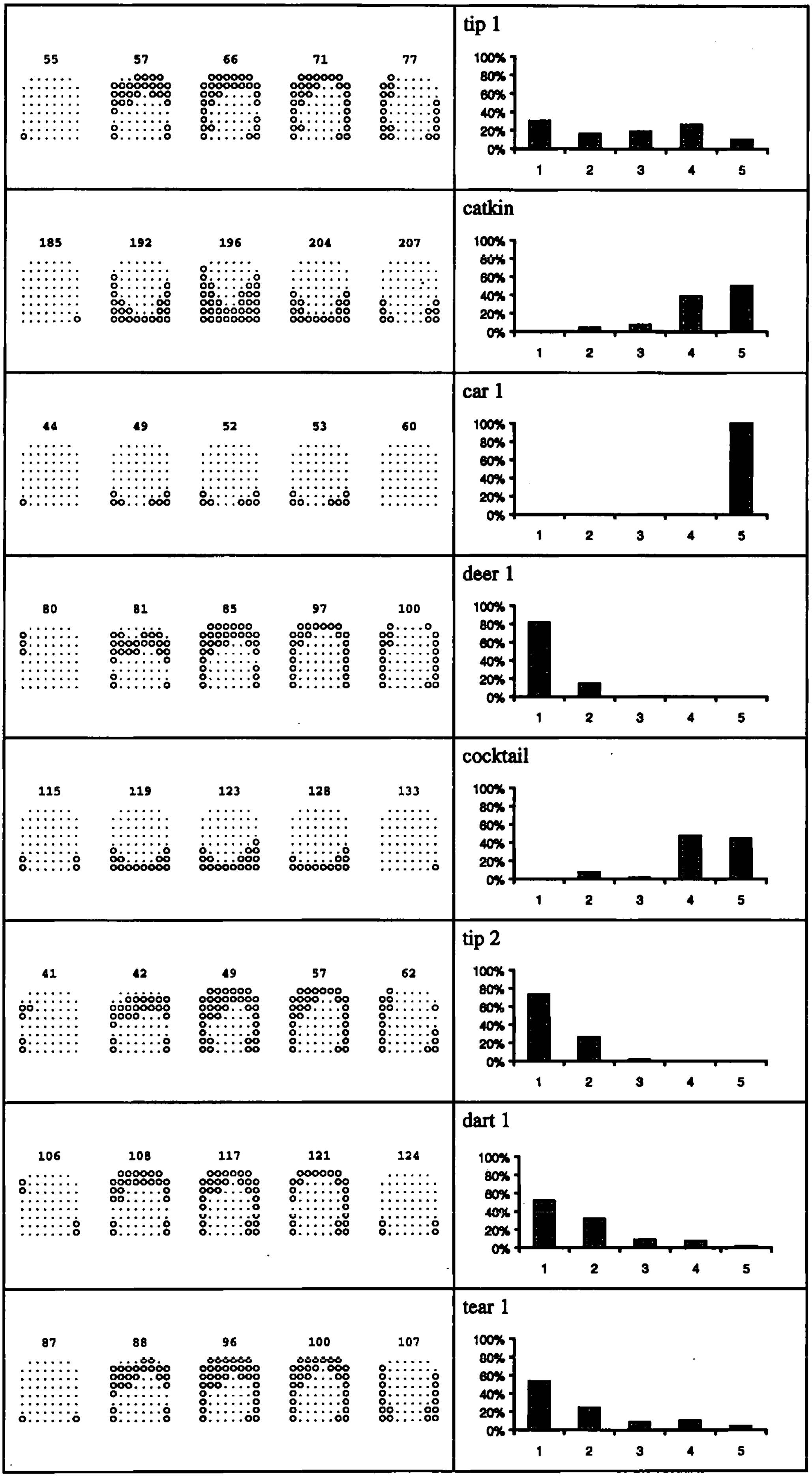


Figure 4-1: 5 reference EPG frames and graphical displays of listener ratings for group 1 words.

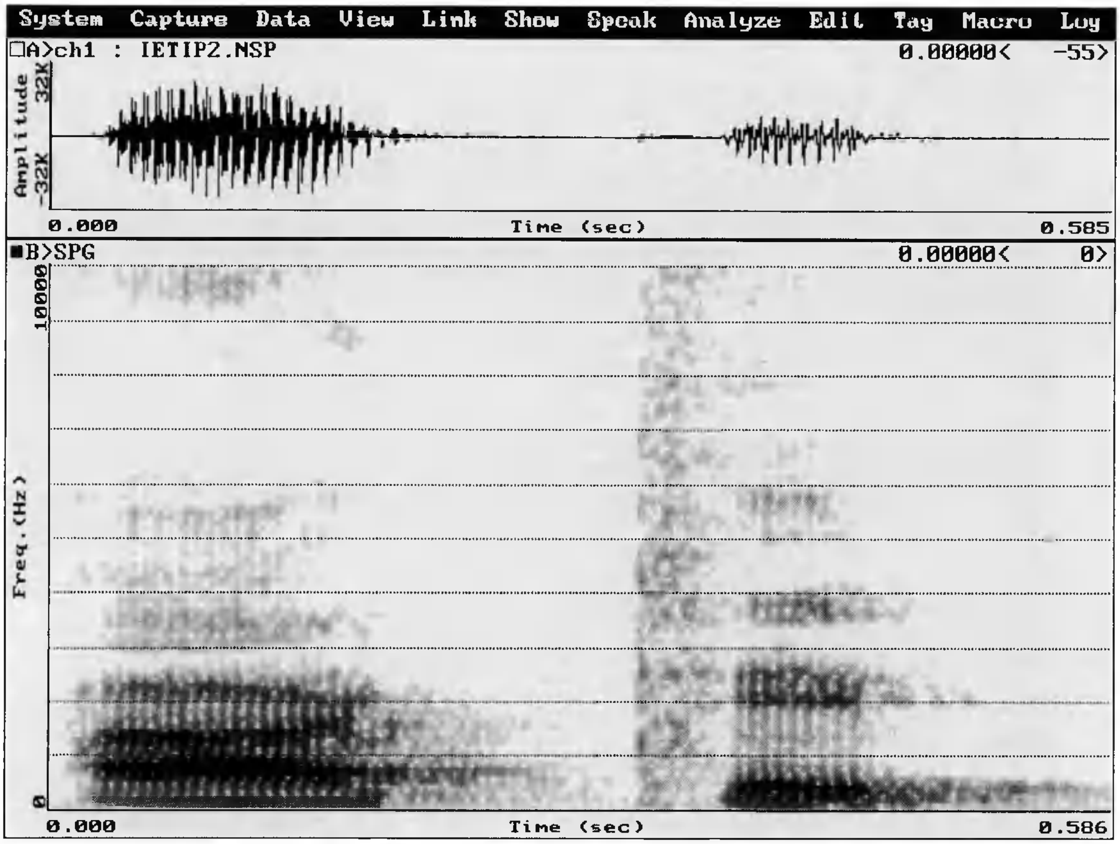


Figure 4-2: Spectrogram for "tip" 1.

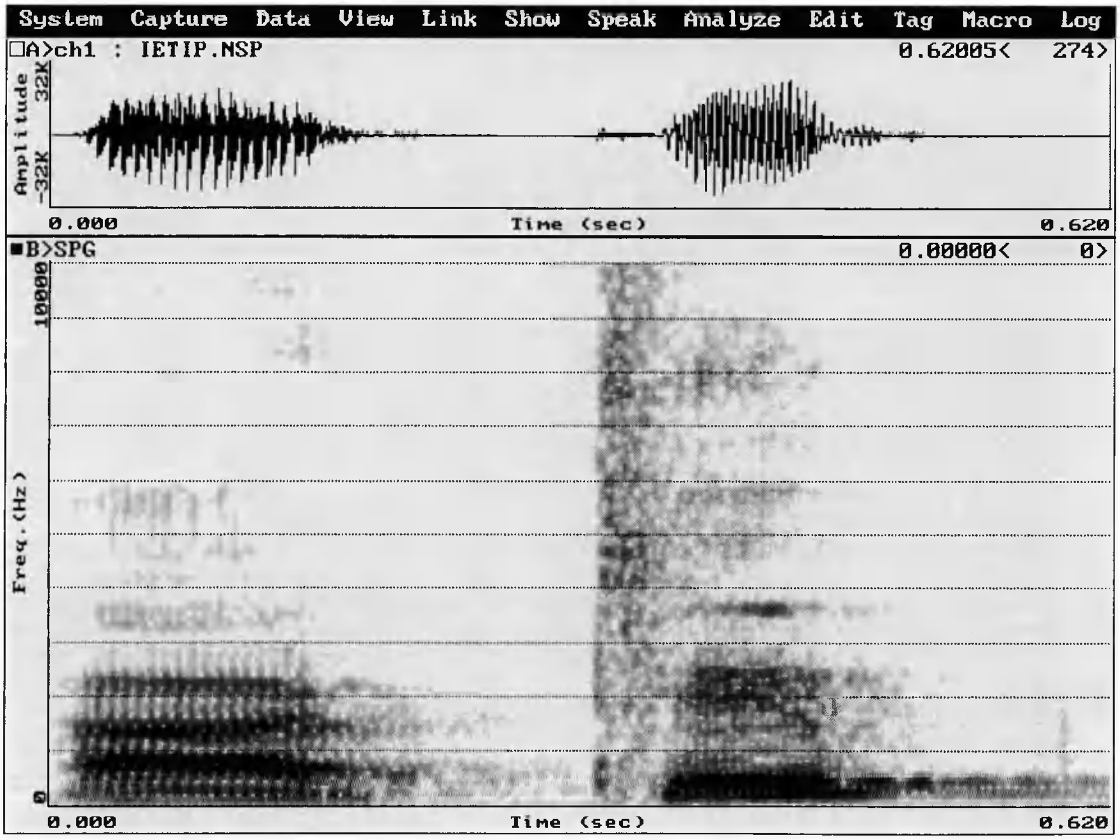


Figure 4-3: Spectrogram for "tip" 2.

4.3.4 Group 2

Alveolar/velar or velar/alveolar substitutions were detected on initial analysis of the DAT recordings for the eight words in group 2. Examination of the EPG data confirmed the transcriptions. All EPG patterns were spatially normal for the substituted alveolar or velar. Occasionally the onset was slightly retracted spatially ("kitkat" 3 and "kitkat" 5) but the frame of maximum contact and release were appropriate for an alveolar plosive. No word had 100% listener agreement. However, 94% of listeners did rate the word initial consonant in "key" 1 as an alveolar. For group 2 words there were more 3 ratings recorded which indicates that the listeners could not identify the sound as either alveolar or velar but at a point midway between the two. This was especially true for repetitions of the word "kitkat" of which there were five different productions. Judgments may have been influenced by the syllable final /t/ in the CVC structure. The listeners may have found it more difficult to focus on the initial consonant when the target final consonant was an alveolar plosive. The frame of maximum contact for all repetitions of "kitkat" in group 2 are essentially similar (see Table 4-7).

Group 2				
54 OOOOOO OOOOOOOO OO....OO O......O ....O O......O O.....OO O.....OO	52 OOOOOO OOOOOOOO OOO...OO OO.....O O......O O......O O.....OO OO...OOO	54 OOOOOO OOOOOOOO OOOO.OOO OOO....O O......O O......O O......O O.....OO	61 OOOOOO OOOOOOOO OOO..OOO OO.....O O......O O......O OO....OO OO...OOO	97 OOOOOO OOOOOOOO OOOO..OO OOO....O O......O O......O O......O O......O
"kitkat" 1	"kitkat" 2	"kitkat" 3	"kitkat" 4	"kitkat" 5

Table 4-7: Frame of maximum contact for productions of "kitkat" 1, 2, 3, 4 and 5.

4.3.4.1 Spectrographic analysis

"Kitkat" 1

Spectrograms for the five different productions of "kitkat" were produced (Figure 4-5, Figure 4-6, Figure 4-7, Figure 4-8, and Figure 4-9 corresponding to "kitkat" 1 to "kitkat" 5 respectively). Since the EPG patterns indicated a substituted alveolar for velar plosive we would expect there to be a concentration of high frequency energy in the spectral bursts for all productions. However, "kitkat" 1 shows a small concentration of energy in the lower frequencies, around 1000 and 2000 hertz more typical of a bilabial production (Kent and Read, 1992; Harrington and Cassidy, unpublished manuscript). This perhaps explains the almost equal distribution of ratings since the listeners were asked to make a guess if they were unsure. If this was the case then the probability of choosing 1, 2, 3, 4 or 5 would be equal. The fact that rating 5 was the least popular is probably related to the lack of lingual contacts in the velar region (see Figure 4-4 "kitkat" 1). For a substituted alveolar plosive we would expect to see a divergence of F2 and F3 leading into the stop and the opposite on release. There is no evidence of this from the spectrograms. This is considered an important cue for perceptual judgments (Kent and Read, 1992).

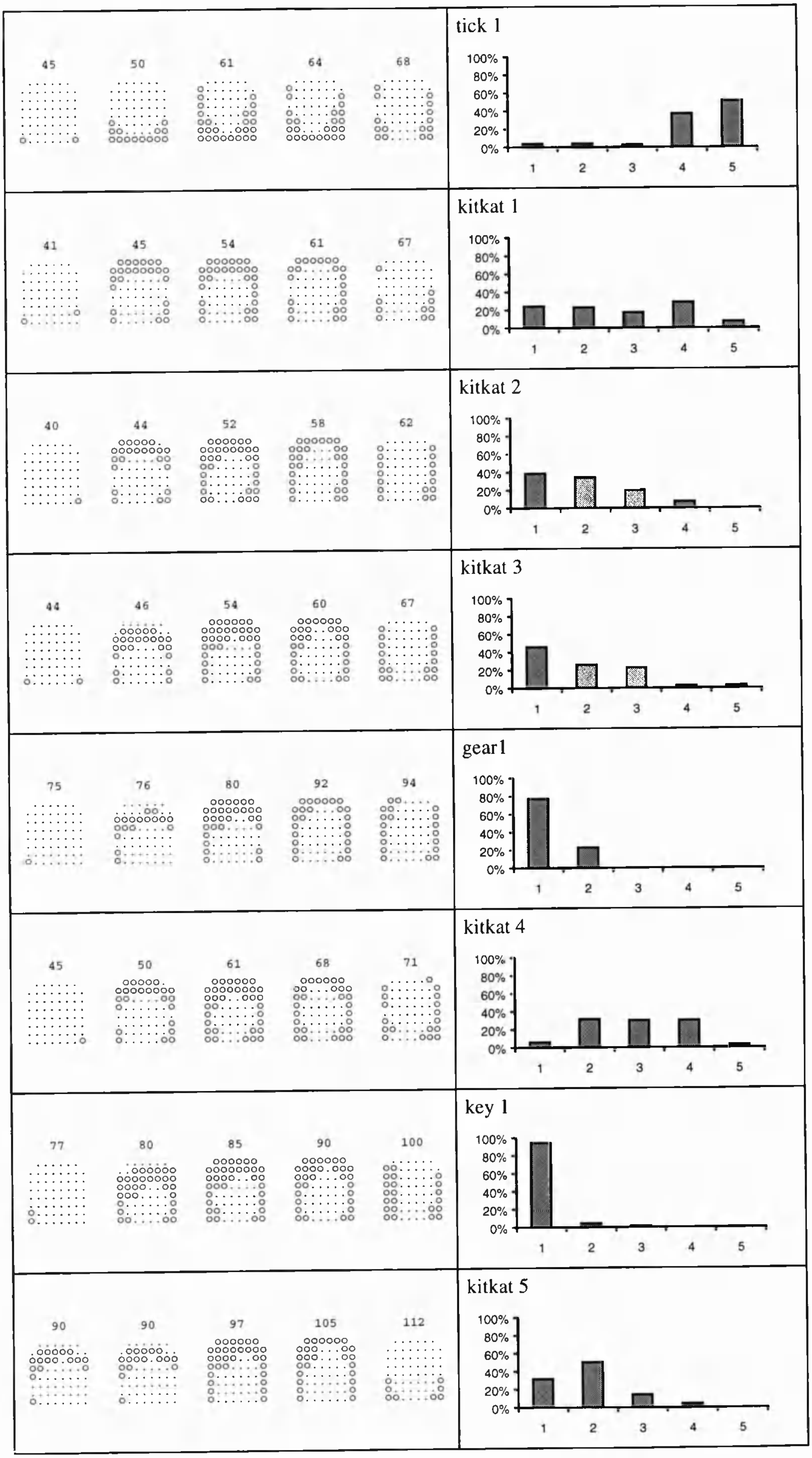


Figure 4-4: 5 reference EPG frames and graphical displays of listener ratings for group 2 words.

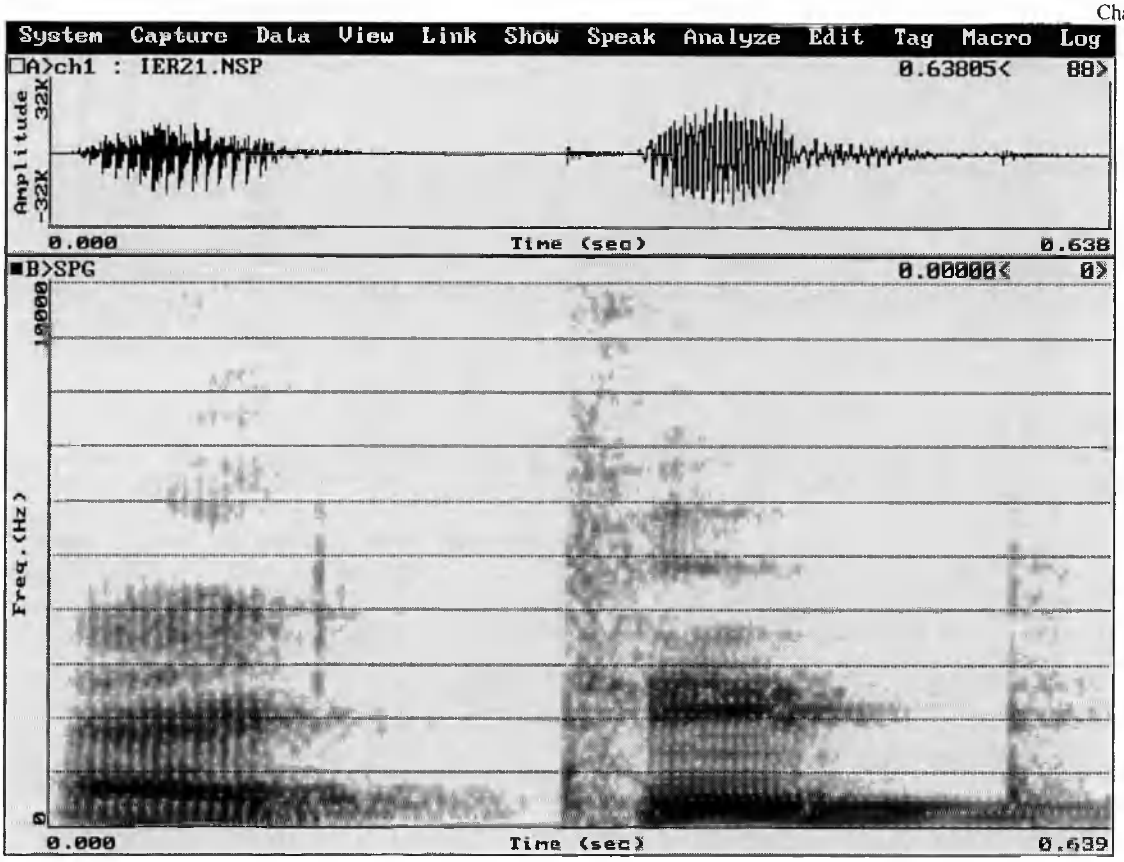


Figure 4-5: Spectrogram for "kitkat" 1.

"Kitkat" 2 and "kitkat" 3

Productions of "kitkat" 2 and "kitkat" 3 show a spread of energy during the spectral burst from 0 through to 7000 hertz. There is no characteristic concentration of high energy for either production which would be predicted from the EPG data which indicates alveolar contact (see Figure 4-6 and Figure 4-7). F2 and F3 transitions are also relatively flat. Despite this, there is a slight trend for listeners to chose a rating indicative of alveolar in preference to velar, seen from the skew on the corresponding graphs (Figure 4-4).

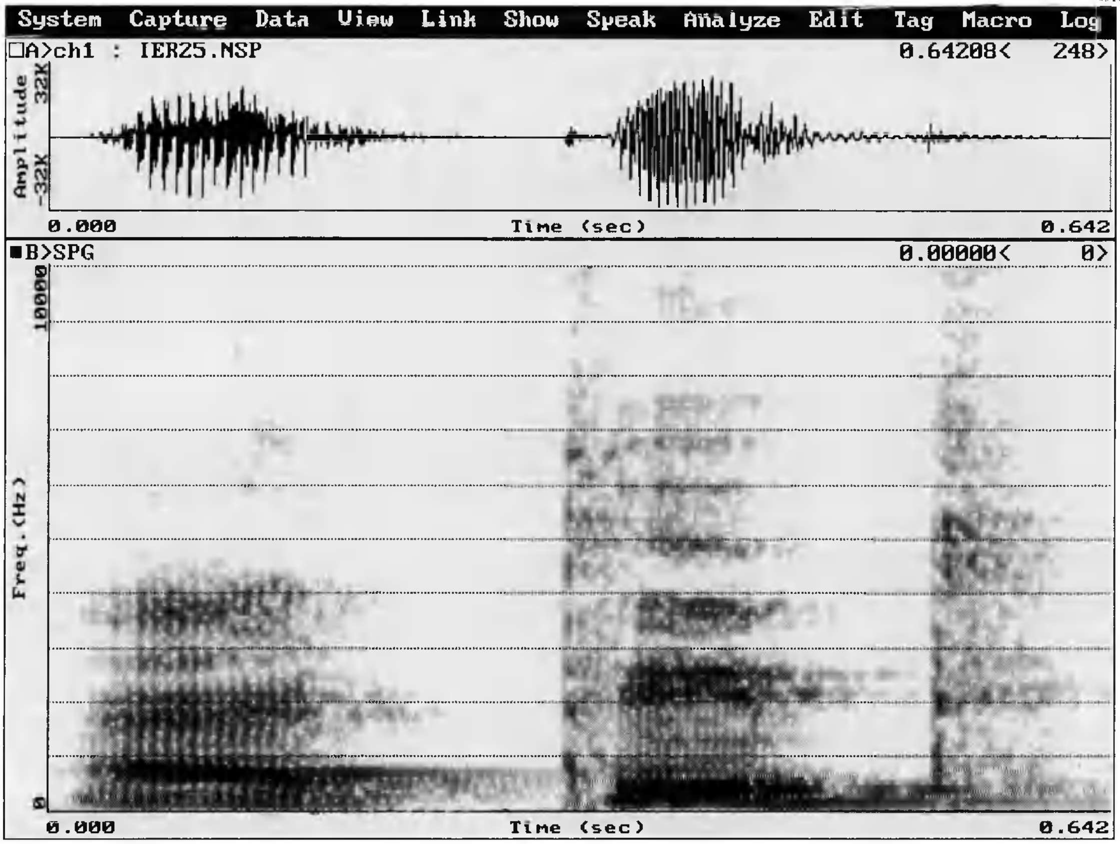


Figure 4-6: Spectrogram for "kitkat" 2.

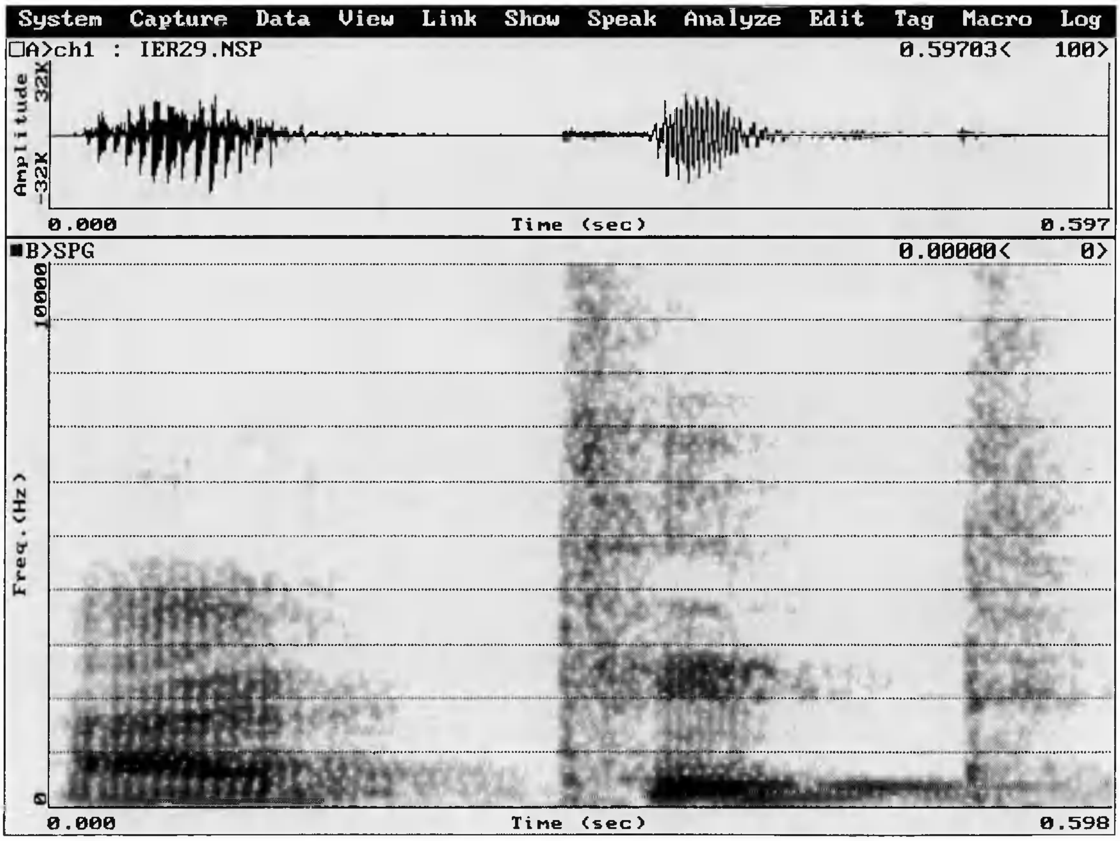


Figure 4-7: Spectrogram for "kitkat" 3.

"Kitkat" 4

The spectral burst for "kitkat" 4 is more typical of a velar articulation since there is a concentration of energy around the mid frequencies (see Figure 4-8). There is also a slight convergence of F2 and F3 leading into the stop. Formant transitions (F2 and F3) following the release are difficult to determine. The VOT is noticeably shorter than the "kitkat" 1 and "kitkat" 3 (Figure 4-5 and Figure 4-7 respectively) which is characteristic of an alveolar plosive. The corresponding EPG patterns are clearly alveolar (see Figure 4-4). The majority of ratings awarded for this item were ratings 2, 3 and 4 (31%, 30% and 30% respectively). These ratings perhaps reflect the conflicting information available from the EPG patterns and spectrographic displays. Only 6 out of the 70 rating judgments were given to either category 1 or 5.

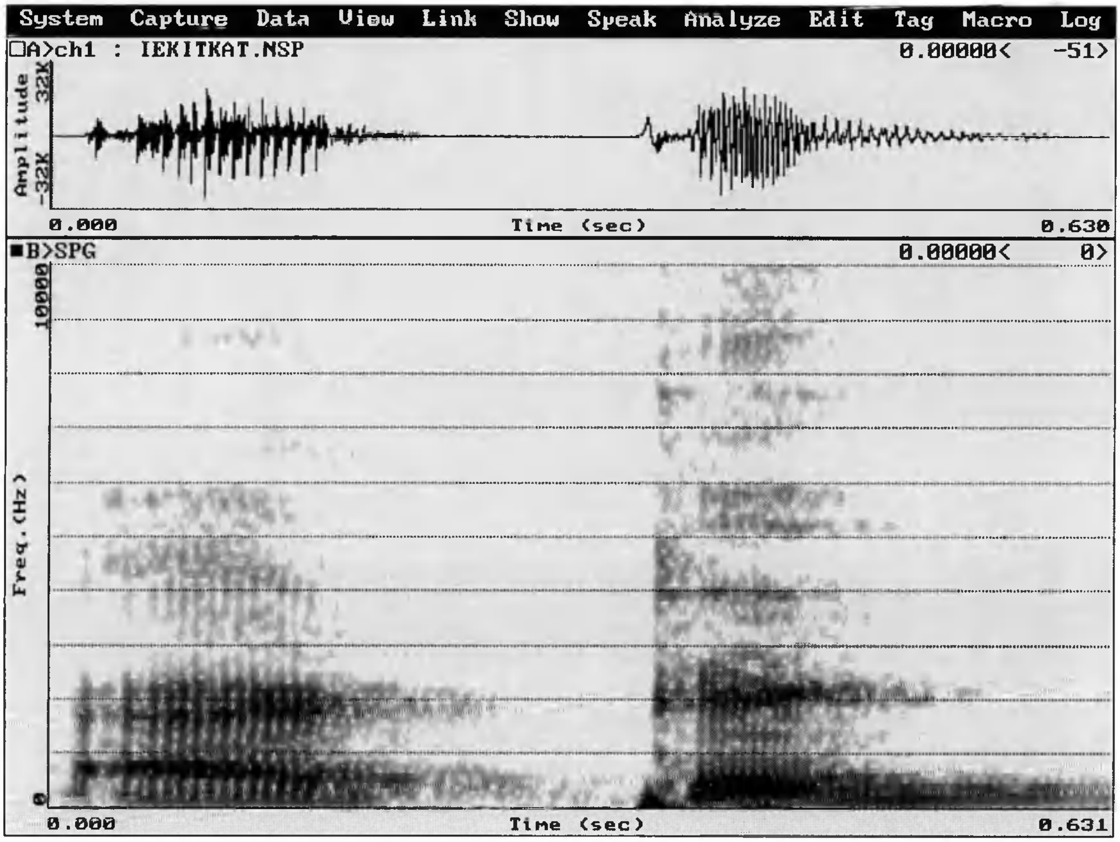


Figure 4-8: Spectrogram for "kitkat" 4.

"Kitkat" 5

Listener judgment ratings for "kitkat" 5 favoured 1 and 2 (81% of total ratings) although some listeners awarded ratings of 3 and 4. Energy at the spectral burst appears to be prevalent in three areas, 0 to 1,000 hertz, 2 to 3,000 hertz, and 5 to 6,000 hertz (see Figure 4-9). Therefore the spectral burst gives little indication of the stop consonant articulated. There is a noticeable divergence of F2 and F3 leading into the stop articulation which is typical of an alveolar plosive. The formants following the release of the stop gesture are very unclear. It is probably the formant transitions prior to the stop coupled with the EPG patterns which cause the listener to favour ratings 1 and 2 (definitely an alveolar and more alveolar than velar respectively). The lack of information in the spectral burst and the longer VOT (typical for velar plosives) is probably influential in the spread of the other ratings as opposed to all listeners marking a clear substitution.

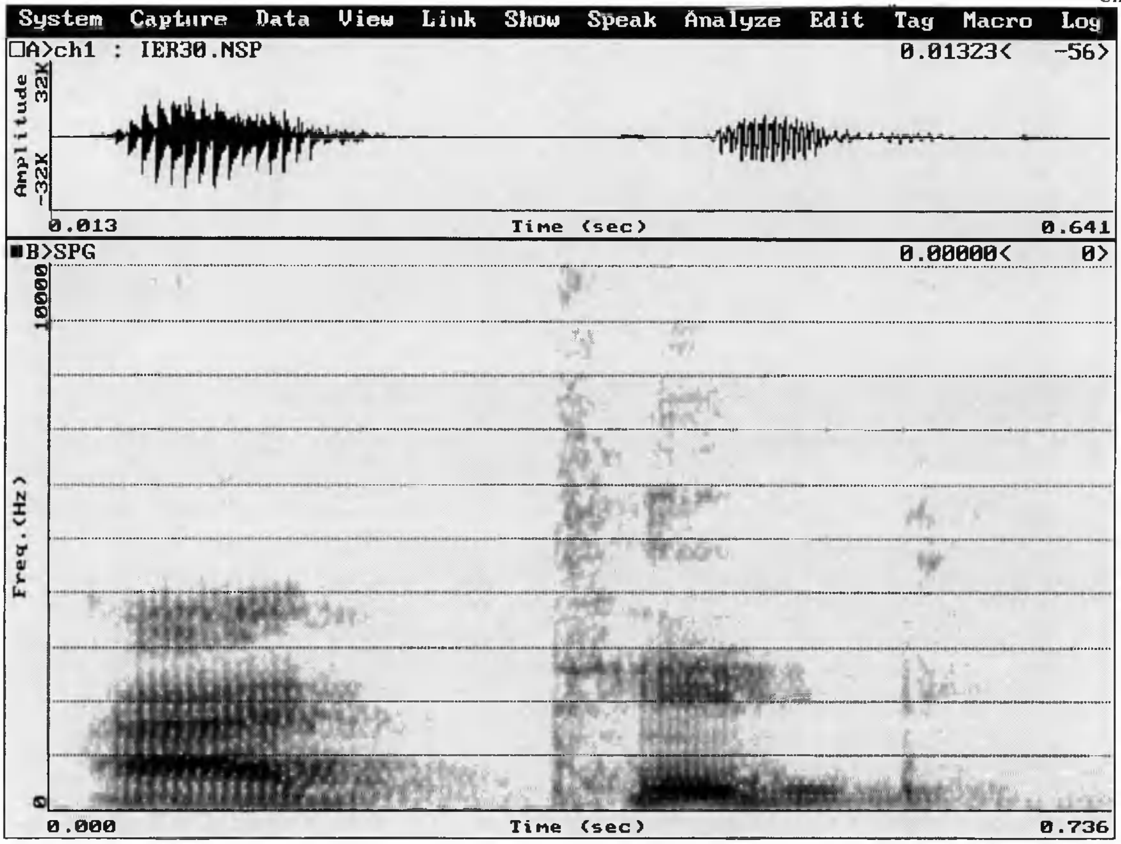


Figure 4-9: Spectrogram for "kitkat" 5.

4.3.5 Group 3

This group of 8 words was chosen because on analysis of the EPG data both alveolar and velar articulations were evident in word initial position with a resulting double articulation. It could be argued that because there were two different lingual articulations there is an equal chance of the listeners choosing any one of the five ratings. If this is true a chi square analysis can be performed since all of the ratings will have an expected value of 14 (total 70 listener judgments divided by 5 possible ratings). If we accept that 14 is the expected value for the ratings then we can test the null hypothesis that there is no real difference between the observed and the expected values. A Chi square analysis was used to test the hypothesis. The calculations are detailed in Appendix B.

The Null hypothesis for all 8 words in group 3 can be rejected at the level $p > 0.05$. Therefore if we take the expected ratings to be equal, that is 14, there is a real difference between the observed and the expected results. However, we might want to suggest that the listeners will perceive the articulation which is released second in the alveolar/velar or velar/alveolar sequence and propose that the spectral burst will be characteristic of this articulation. This being true, no statistical tests can be applied since there will be expected values of zero. Therefore, the data must be taken at face value.

“Key” 2 and “car” 2

Figure 4-10 shows the specified EPG frames and the corresponding graphs for listener ratings. Despite the double articulations, “key” 2 and “car” 2 show very high listener agreement. Furthermore, most of the listeners chose either definitely an alveolar (96%) for “key” 2 or definitely a velar (94%) for “car” 2. These ratings correspond to the stop which was released second in the sequence.

The spectrograms for these two words (Figure 4-11 and Figure 4-12 respectively) show very definite high frequency energy during the spectral bursts. For "key" 2 (Figure 4-11) this dominates the higher frequencies. This is appropriate for an alveolar which reflects the judgments of the majority of listeners. For "car" 2 (Figure 4-12) the energy is concentrated at a lower frequency. This is appropriate for a velar plosive which most listeners detected. Formant transitions following the stop burst are unclear. However, prior to the stop closure both show a clear convergence of F2 and F3 characteristic of velar plosives. Based on the perceptual judgments this is surprising for "key" 2 since an alveolar was perceived and the formant transition is characteristic of a velar. However, a convergence of F2 and F3 prior to the consonant is typical for a velar articulation. "Car" 2 was heard as a velar by 94% of listeners which is perhaps unsurprising since the formant transitions leading into the stop suggest a velar plosive. Higher formants are clearly visible for "car" 2 (Figure 4-12) but are absent for "key" 2 (Figure 4-11). Perhaps these higher formants are also important for perceptual judgments.

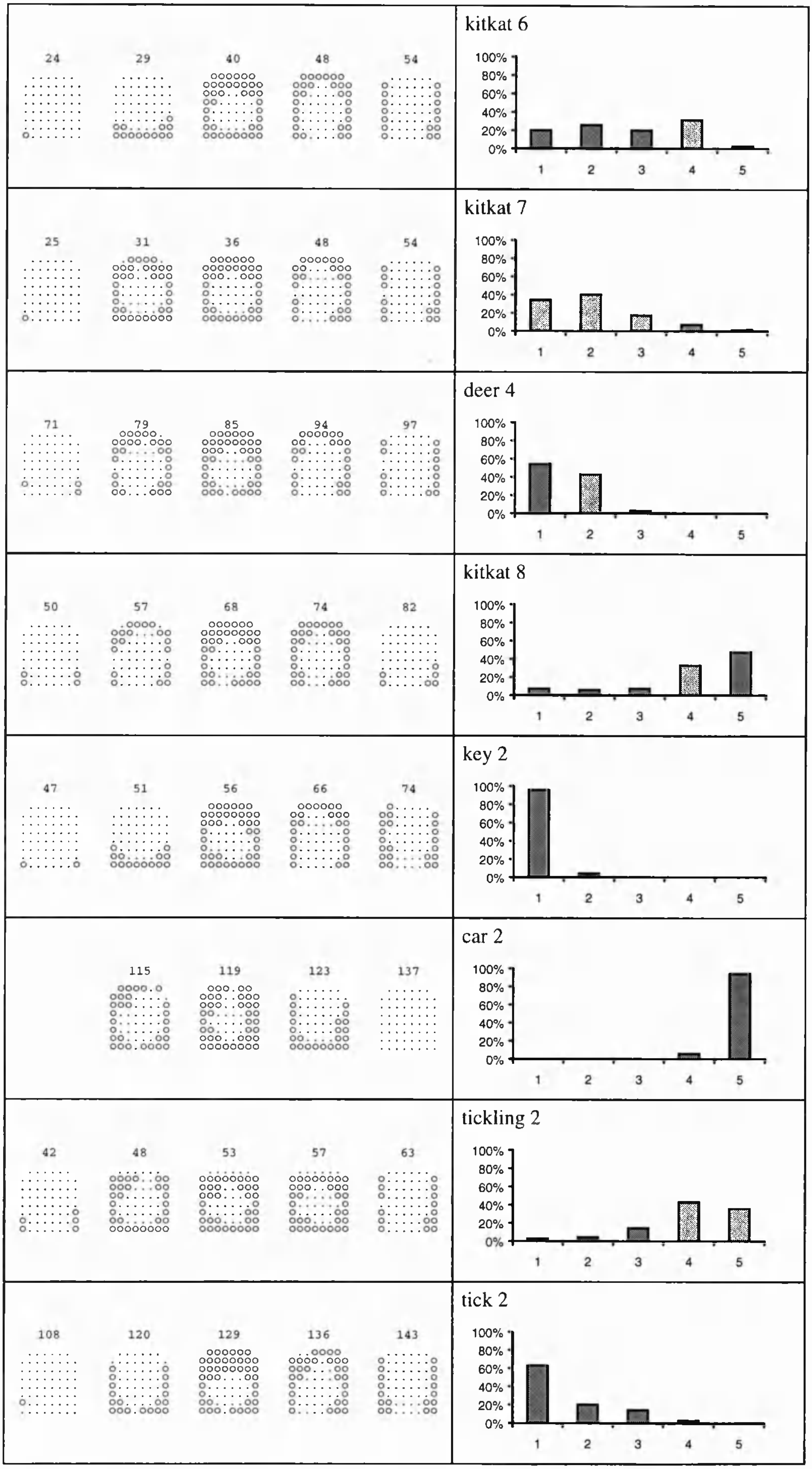


Figure 4-10: 5 reference EPG frames and graphical displays of listener ratings for group 3 words.

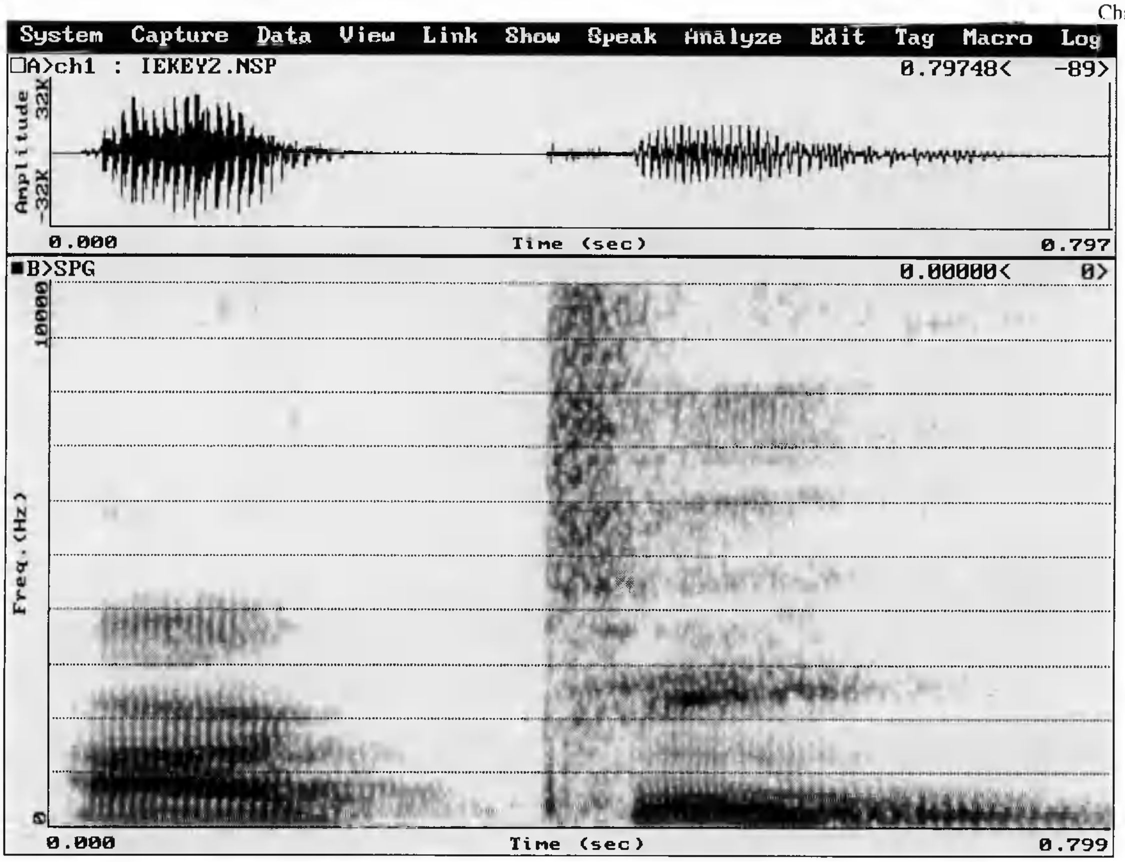


Figure 4-11: Spectrogram for "key" 2.

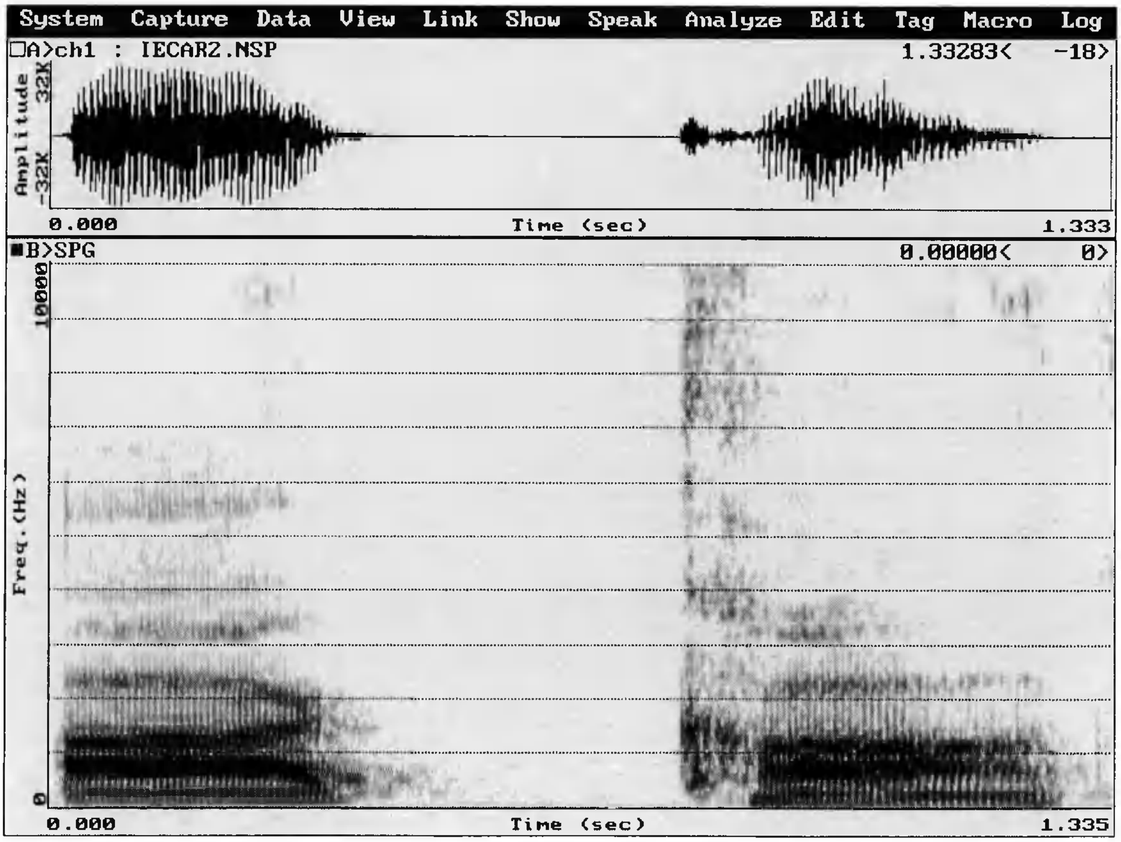


Figure 4-12: Spectrogram for "car" 2.

"Kitkat" 6 and "kitkat" 8

All the graphs (Figure 4-10) except that for "kitkat" 6 show a skew towards either alveolar or velar. Typically the skewness was reflective of the articulation released second as expected. Surprisingly though, more listeners rated "kitkat" 8 as a velar despite the final release of lingual contact being an alveolar. Inspection of the spectrogram (Figure 4-13) may explain why since there is a convergence of F2 and F3 leading into the stop and a low to mid frequency dominance which are both characteristic of a velar plosive. Movement of the formants following release is very unclear.

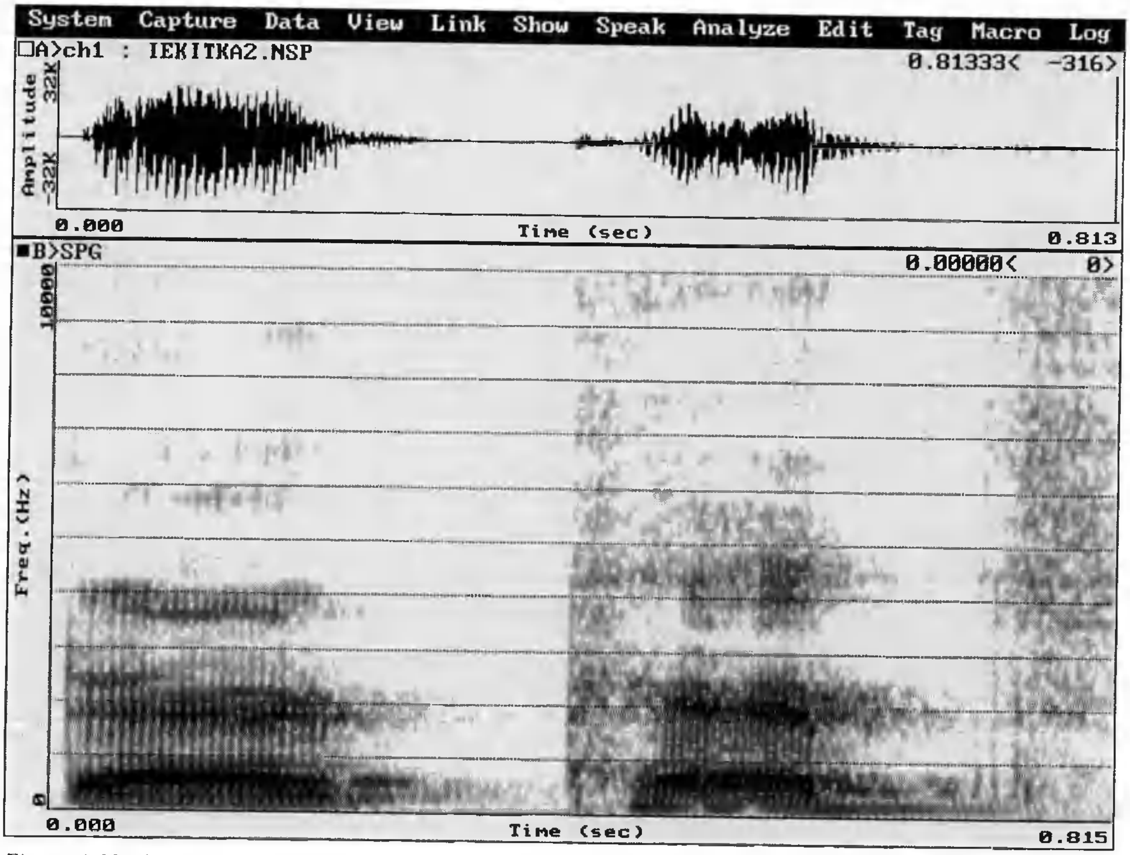


Figure 4-13: Spectrogram for "kitkat" 8.

The inter-subject reliability analysis revealed strong agreement between listeners for all words except "kitkat" 6 where a standardized item alpha score of 0.4772 suggested only weak agreement. Listener judgments fell fairly equally across all ratings except 5 which was chosen only 3% of the time. The lack of high energy during the spectral burst and the unclear formant traces for the corresponding spectrographic display (Figure 4-14) are possible reasons for the weak listener agreement. There appears to be little information to suggest either an alveolar or a velar plosive from the spectrographic display.

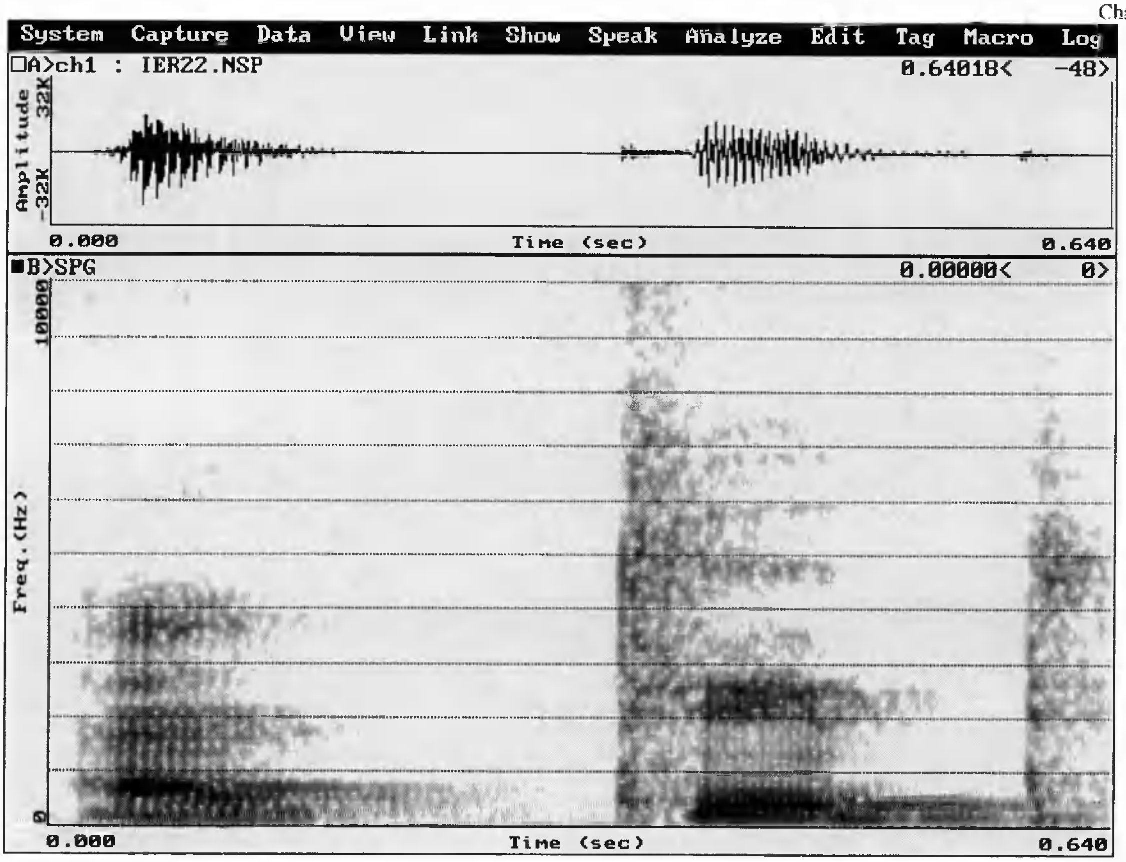


Figure 4-14: Spectrogram for "kitkat" 6.

4.3.6 Summary

Results from this small study which investigated the relationship between phonetic transcriptions and EPG patterns suggest that, despite the production of clear alveolar or velar lingual/palatal contact patterns evident from the EPG data, listeners rarely perceived either a clear alveolar or velar articulation. This may be an effect of the design of the investigation. It would be interesting to see the results if only 2 categories were available, alveolar and velar. Would there have been 100% listener agreement and secondly, would listeners have chosen the articulation which was seen from the EPG trace, or in the case of group 3 words (double articulations) the articulation released second?

Listeners tended to make categorical decisions for words in group 3. Therefore most did not detect the presence of two gestures. Presumably if they had there would have been more rating 3's indicating neither a clear alveolar or clear velar but a sound at a point midway between the two. These results have important consequences for diagnosis and therapeutic intervention. If articulations are being misperceived then an incorrect diagnosis of the speech disability is likely. Since treatment procedures are usually made from perceptual, not acoustic or instrumental analysis, it is important that diagnoses are accurate. If, as Ziegler and Hoole (1989) state, there is a psychological component associated with auditory analysis which causes the listener to favour "categorical" (paraphasic) errors over "non-categorical" (distortions) then inappropriate treatment procedures may result. If we assume that a subject is producing phonemic paraphasic errors when in fact the productions are distortions then treatment procedures will be based on linguistic disruption. However, if the error is at the level of motor programming therapy is unlikely to be efficacious.

Chapter 5

5. Results 1: Classification Of Speech Sound Errors Identified Through Auditory-Based Analysis

5.1 Introduction

There have been several attempts to classify perceived speech sound errors made by those with acquired neurogenic disorders (Blumstein, 1973; Weismer & Liss, 1991; Mackenzie, 1982; Miller, 1995). Under investigation have been subjects variously described as fluent versus non-fluent, anterior versus posterior patients, and those diagnosed with apraxia of speech (sometimes, but not always, considered synonymous with Broca's aphasia) compared to those demonstrating phonemic paraphasic errors. The range of taxonomies has also varied considerably both in the terminology and in the complexity of the classification of error schemes adopted. Most studies have pre-selected subjects on the basis of a speech diagnosis already given. Other methodological variants include sample size, method of speech elicitation, different aetiologies, time since onset, severity of speech disorder, transcription conventions (narrow versus broad phonetic transcriptions) and methods of analysis. It is unsurprising therefore that attempts to differentially diagnose subjects based on these error analyses have resulted in conflicting findings. For example, some have suggested that errors of substitution are the most common type of error made by apraxic speakers (Johns and Darley, 1970; Blumstein, 1973; Trost and Canter, 1974; Darley et al., 1975; Monoi, Fukusako, Itoh, Sasanuma, 1983; Itoh and Sasanuma, 1984; Canter et al., 1985; Washino et al., 1981; Rosenbek and McNeil, 1991) whilst others have suggested that errors of distortion are the most frequently occurring errors in apraxic speech (Odell et al., 1990a; Square et al., 1982).

This section looks at three different methods of perceptual analysis previously employed and considers the advantages and restrictions of each. From these observations a new system of analysis is suggested for preliminary analysis of the data that is later compared to the EPG data. The three systems of analysis to be considered are Blumstein (1973) Mackenzie (1982) and Miller (1995). Each will be summarized and evaluated separately.

5.1.1 Blumstein's classification (1973)

Blumstein, (1973) investigated 17 aphasic adults variously diagnosed as either Broca's, Wernicke's or conduction aphasics at least 8 weeks post onset. Speech samples took the form of spontaneous speech, a minimum of 2000 words required. Therefore the samples were not identical in either their content or length. The speech samples were listened to and any phonological errors were transcribed. No detail is given on who transcribed the speech samples or whether transcriptions were broad or narrow. Only those words where the target was discernible were used in the analysis and phonetic distortions were eliminated. No rationale for the elimination of these errors is given. The errors were then classified into four main groups as follows (definitions with examples and Blumstein's transcriptions taken from Blumstein, 1973: p.37-38):

A. Phonemic substitutions - the substitution of one phoneme for another (/timz/ 'teams' → /kimz/. /taim/ 'time' → /tain/).

B. Simplification - the loss of a phoneme or a syllable (phoneme simplification, /pɹIti/ 'pretty' → /plti/, syllable simplification, /EkspEnsIv/ 'expensive' → /pEnsIv/).

C. Addition - the addition of an extra phoneme or syllable in a word (addition of a phoneme, /papa/ 'papa' → /papra/, addition of a syllable /hElp/ 'help' → /hEləp/).

D. Environment - this was subdivided into 3 types of phonemic substitution which could be related to surrounding phonemes:

1. Intramorphemic blends, both regressive (/krit/ 'Crete' → /trit/) and progressive (/čæmpiənšIps/ 'championships' → /čæčInšIps/).

2. Intermorphemic blends, errors triggered by phonemes or syllables located in neighbouring words (/rost bif/ 'roast beef' → [ɹof bif]) and (/ai θiŋk so/ 'I think so' → /ai siŋk so/). These errors were also sub-categorized into errors of progressive and regressive assimilation.

3. Metathesis - the inversion of the ordering of phonemes in a given sequence (/dəgriz/ 'degrees' → /gədriz/).

Whilst this system of classifying errors is simple and easy to replicate, it has its limitations. Firstly, since phonetic distortions were eliminated, errors such as /s/ → [sʲ], for example, were ignored. However, errors of distortion have been regarded by some to be indicative of a speech apraxia (Odell et al., 1990a; Square et al., 1982) and therefore their inclusion in a classification scheme is important. Secondly, it treats environmental errors separately from other error types even though these may also be regarded as errors of substitution, addition or omission. For example "skirt" heard as [steɹt] would presumably be described as an intramorphemic blend under group D (Environment). In later figures, graphical displays and discussions concerning substitutions Blumstein refers only to sub group A (phonemic substitutions). Therefore when looking at percentage of error types (Blumstein, 1973: p.47) the category "substitution" is misleading since it does not include the substitutions resulting from environmental influences. Therefore, we might suggest that the substitutions recorded in sub group D be included alongside errors in sub group A when considering percentage of error types. Furthermore, there is no definition for the term "surrounding phonemes" under the heading "Environment". Since the errors are taken from spontaneous speech samples it is necessary to specify what the maximum plausible distance for influence is. Finally, because the errors are taken from the conversational speech samples determining the source of the phonological error is problematic. It is more difficult to be definite about the source of the error because we cannot be certain whether there are any semantic or syntactic influences. In contrast, productions taken from subjects who have been required to produce single words do not include these linguistic influences.

5.1.2 Mackenzie's classification (1982)

Mackenzie (1982) tested the hypothesis that "aphasic subjects whose speech contains articulatory phonemic errors are not a homogenous group phonologically" (p.28). In her study of 48 fluent and non-fluent aphasics she looked at the differentiation of what she calls "aphasic articulatory defect" and "aphasic phonological defect". Speech samples consisted of 50 one and two syllable words. Three methods of presentation of the stimuli were adopted: imitation; picture naming; and reading. All words were transcribed using the International Phonetic Alphabet (IPA) but no further detail on narrowness of transcription or who the transcriber(s) was is given.

Classification of errors are detailed in Table 5-1.

	Target word	
ERROR CLASSIFICATION	"fish" [fɪʃ]	"sleeping" [slipiŋ]
Substitution	[tɪʃ]	[stipiŋ]
Omission	[ɪʃ]	[lipiŋ] [sipiŋ]
Distortion	[ɸɪʃ]	[çlipiŋ]
Environmental Replacement	[ʃiʃ] [fɪf] [ʃɪʃ]	[spiliŋ] [sliliŋ]
Addition	[flɪʃ]	[sklipiŋ]
Compound	[klɪʃ] [tɪf]	[çtipiŋ] [skwipiŋ]
Replacement by reduction	-	[tipiŋ]

Table 5-1: Mackenzie's classification scheme (1982).

In addition to the above classification scheme, Mackenzie also scored repetitions, retrials and miscellaneous errors. The latter category included non speech rehearsals, blocks/prolongations, lexical errors, word perseverations, automatisms, failures to respond, and unrecognizable or bizarre responses. Mackenzie's taxonomy can be seen to be more elaborate than Blumstein's since there are more categories allowing greater subdivision of errors. Furthermore, she allows for errors of distortion to be classified as such. In theory, a more detailed classification of the phoneme errors should assist in differential diagnosis. However, despite the addition of some categories, Mackenzie's system of classification has certain limitations felt to be important for perceptual analysis. The category of "environmental replacement", similar to Blumstein, is separated from the substitution category even though the errors listed here are errors of substitution. Whilst it is important to note that the error arose as a result of environmental influences, it is also important to specify in more detail the type of error if these error analyses are going to be used to assist differential diagnosis. Percentage totals of the type of error are inaccurate since many of the substitutions are not marked under the category "substitution". Therefore the number of substitutions made by any one subject may be lower than the actual incidence. Furthermore, Mackenzie's "environmental replacement" errors related only to errors of substitution. But influences from neighbouring phonemes and syllables could equally result in other types of errors, for example additions and distortions. The category "compound errors" also fails to specify the details of the error. By compound, Mackenzie is suggesting that the word has undergone more than one process. For example, "fish" → [kliʃ] is presumably a result of both substitution and addition. By marking this as a compound error the individual processes involved are not classified. Again, this will affect any calculations involving percent of error types.

5.1.3 Miller's classification (1995)

Miller (1995) addressed these issues by suggesting a more detailed and elaborate taxonomy. He designed a "taxonomy of listener-perceived derailments that would cover the range of 'errors' reported to characterize and differentially diagnose 'motor' speech disorders" (p. 348). Thirty neurologically disordered speakers (6 spastic dysarthric; 12 speech dyspraxic and phonemic paraphasic without dysphasia; 12 speech dyspraxic and phonemic paraphasic with dysphasia) produced single words in naming and repetition tasks. Their responses were subjected to narrow phonetic transcription and an error analysis based on the final whole word attempt was made. Miller lists 27 different error types. Substitutions, distortions, omissions, additions, perseverations, and metathesis were not single categories but instead subdivided in an attempt to tease out subtle differences between subjects. For example, substitutions could be either anticipatory non-contiguous, perseveratory non-contiguous, anticipatory contiguous, perseveratory contiguous, they could occur across a categorical boundary or with no apparent source in the sound environment. However, on evaluation of this more extensive classification system Miller states "As to whether an expanded taxonomy adds more diagnostically useful information, the answer, from a group perspective, is apparently no" (p.356). He goes on to say "analyses in the end had to rely largely on the error types previously employed as a result of the absence or paucity of examples in many categories" (p.356). Before any statistical analyses could take place Miller had to make a number of modifications to the classification scheme he proposed. These included collapsing anticipatory, perseveratory and transposition derailments into one category, namely displacements, and combining all non displacement substitutions into one category. Distortions, omissions, and additions remained separate.

5.1.4 Wood's classification (1996)

With the above in mind, a classification scheme was devised to characterize the speech sound errors made by the 10 aphasics in this study. The speech samples consisted of the 2 word lists and repetition task (46 words repeated twice, plus three words repeated 10 times totaling 122 words, with the exception of MU where total words recorded onto DAT was 91, and BA total words was 92). Narrow phonetic transcriptions were made by the author of all the words using IPA symbols (revised to 1993) plus extended IPA symbols (revised to 1994). Error analysis was on the final whole word attempt corresponding to the target. The aim was to make a taxonomy comprehensive enough to separate errors of different sources yet at the same time a system easily replicable by others. The perceived errors would later be related to the corresponding EPG patterns. Environmental influences for substitutions, distortions, and additions were considered important if the source of the error was to be hypothesized. Errors of metathesis were also listed as substitution where appropriate. When a production seemed so distant from the target, such that the target became unclear, these productions were marked as unrecognizable productions. The categories used are described in detail below and summarized in Table 5-2 with examples.

1. Substitutions: The replacement of one phoneme by another. If the substituted phoneme shared place of articulation with another in the word it was classified as an environmental substitution (e.g. "tick" → [kʰɪk], "tractor" → [kɹaktə]). If it was unrelated to any other phoneme then it was considered to be a non environmental substitution (e.g. "tick" → [bɪk], "tractor" → [fɹaktə]).

2. Omissions: The deletion of a consonant in any word position (e.g. "tick" → [ɪk], "tractor" → [kʰaktə], [ɹatə]).

3. Distortion: The production of a sound which is not considered to be native to the language or of a phoneme which has been altered in some way such that it is considered deviant. If the distortion is related to another phoneme in the word it was considered environmental (e.g. "tick" → [tˠɪk], "tractor" → [tˠɹaktə]), unrelated distortions were marked as non environmental (e.g. "tick" → [tⁿɪk], "tractor" → [tⁿɹaktə]).

4. Addition: The production of an extra phoneme or syllable in a word. If this additional phoneme shared its place of articulation with another in the target word then it was considered to be an environmental addition (e.g. "tick" → [tʰɪkt], "tractor" → [kɹaktə]). If it appeared unrelated to the word it was classified as non environmental (e.g. "tick" → [tʰɪpk], "tractor" → [sɹaktə], [ɹakətə]).

5. Replacement by Reduction: Cluster reduction by substitution (e.g. "tractor" → [paktə]).

6. Metathesis: An alteration in the sequencing of phonemes (e.g. "tick" → [kʰɪt], "tractor" → [kɹattə]).

7. Reiteration: Repeated use of a phoneme(s) typical of non-fluency (e.g. "tick" → [t/t/tʰɪk], "tractor" → [t/t/ɹaktə], [ɹ/ɹ/ɹaktə]).

8. Unrecognizable response: A response holding no obvious phonemic or semantic relationship with the target word (a neologism) (e.g. "tick" → [sel], "tractor" → [kʰipnəl]).

	Target word	
Error classification	"tick" - [tɪk]	"tractor" - [tɹaktə]
Substitution - environmental	[kʰɪk]	[kɹaktə]
Substitution - non environmental	[bɪk]	[fɹaktə]
Omission	[ɪk]	[kʰaktə]
Distortion - environmental	[tˠɪk]	[tˠɹaktə]
Distortion - non environmental	[tʰɪk]	[tʰɹaktə]
Addition - environmental	[tʰɪkt]	[ktɹaktə]
Addition - non environmental	[tʰɪpk]	[stɹaktə]
Replacement by reduction	-	[paktə]
Metathesis	[kʰɪt]	[kɹattə]
Reiteration	[t/t/tʰɪk]	[t/t/tɹaktə], [tɹ/tɹ/tɹaktə]
Unrecognizable response	[sel]	[kʰipnəl]

Table 5-2: Wood's classification scheme (1996).

5.1.5 Summary of error classifications

Results from the new error classification (Wood 1996) can be seen in Table 5-3 and Table 5-4. Table 5-3 gives the actual number of times each error occurred, Table 5-4 gives the type of error as a percentage of the total number of errors. The data was also analysed according to Mackenzie's (1982) classification scheme for purposes of comparison (Table 5-5 and Table 5-6). This taxonomy was chosen over Blumstein (1973) and Miller (1995) for two reasons. Firstly, Blumstein's analysis eliminated errors of distortion which were felt to be important especially since the literature disagrees on the prevalence of these errors in different aphasic syndromes. Secondly, since Miller (1995) stated that his expanded taxonomy did not add "more diagnostically useful information" (p. 356) it was felt that the proposed classification scheme was too detailed to be of any benefit to the restricted corpus of data from this investigation, with many of the categories remaining redundant.

Subject	Diagnosis	Env. Sub.	Non Env. Sub.	Env. Dist.	Non Env. Dist.	Env. Add.	Non Env. Add.	Omission	Metathesis	Reiteration	Unrec. Resp.	R By R	Total
FM	Broca's/AOS	5	10	3	23	3	12	5	0	1	0	0	62
MU	Broca's/AOS	17	20	1	8	1	8	2	0	2	8	0	67
BA	Broca's	11	0	3	8	4	4	0	2	3	0	0	35
CR	Broca's	8	10	12	17	5	6	5	0	1	0	6	70
JM	Broca's	8	10	7	9	2	1	2	0	0	0	1	40
IE	conduction	17	16	3	7	3	7	2	2	6	0	0	63
PW	conduction	0	4	0	2	1	5	0	0	1	0	0	13
FC	anomic	0	11	0	6	0	4	4	0	0	0	0	25
HJ	anomic	2	13	1	16	0	10	2	0	1	0	1	46
HL	anomic	2	2	0	3	2	6	0	0	1	0	0	16

Table 5-3: Number of errors according to Wood's error classification (1996).

Subject	Diagnosis	Env. Sub.	Non Env. Sub.	Env. Dist.	Non Env. Dist.	Env. Add.	Non Env. Add.	Omission	Metathesis	Reiteration	Unrec. Resp.	R By R	Total
FM	Broca's/AOS	8.06	16.13	4.84	37.10	4.84	19.35	8.06	0.00	1.61	0.00	0.00	100
MU	Broca's/AOS	25.37	29.85	1.49	11.94	1.49	11.94	2.99	0.00	2.99	11.94	0.00	100
BA	Broca's	31.43	0.00	8.57	22.86	11.43	11.43	0.00	5.71	8.57	0.00	0.00	100
CR	Broca's	11.43	14.29	17.14	24.29	7.14	8.57	7.14	0.00	1.43	0.00	8.57	100
JM	Broca's	20.00	25.00	17.50	22.50	5.00	2.50	5.00	0.00	0.00	0.00	2.50	100
IE	conduction	26.98	25.40	4.76	11.11	4.76	11.11	3.17	3.17	9.52	0.00	0.00	100
PW	conduction	0.00	30.77	0.00	15.38	7.69	38.46	0.00	0.00	7.69	0.00	0.00	100
FC	anomic	0.00	44.00	0.00	24.00	0.00	16.00	16.00	0.00	0.00	0.00	0.00	100
HJ	anomic	4.35	28.26	2.17	34.78	0.00	21.74	4.35	0.00	2.17	0.00	2.17	100
HL	anomic	12.50	12.50	0.00	18.75	12.50	37.50	0.00	0.00	6.25	0.00	0.00	100

Table 5-4: Error incidence as a percentage of the total number of errors according to Wood's error classification (1996).

Key for Table 5-3 and Table 5-4: Env. Sub. - Environmental substitution; Non Env. Sub. - Non environmental substitution; Env. Dist - Environmental distortion; Non Env. Dist. - non environmental distortion; Env. Add. - Environmental addition; Non Env. Add. - Non environmental addition; Unrec. Resp. - Unrecognizable response.

Subject	Diagnosis	Substitution	Distortion	Omission	Env. Replace.	Addition	Compound	R By R	Total
FM	Broca's/AOS	8	14	2	0	13	13	0	50
MU	Broca's/AOS	11	1	1	0	3	14	0	30
BA	Broca's	4	17	0	2	6	1	0	30
CR	Broca's	16	14	1	0	8	13	1	53
JM	Broca's	6	7	3	1	2	8	1	28
IE	conduction	13	13	0	2	6	14	0	48
PW	conduction	3	0	0	0	5	3	0	11
FC	anomic	11	7	2	0	1	0	0	21
HJ	anomic	12	16	2	0	5	9	0	44
HL	anomic	4	4	0	0	8	0	0	16

Table 5-5: Number of errors according to Mackenzie's error classification (1982).

Subject	Diagnosis	Substitution	Distortion	Omission	Env. Replace.	Addition	Compound	R By R	Total
FM	Broca's/AOS	16.00	28.00	4.00	0.00	26.00	26.00	0.00	100
MU	Broca's/AOS	36.67	3.33	3.33	0.00	10.00	46.67	0.00	100
BA	Broca's	13.33	56.67	0.00	6.67	20.00	3.33	0.00	100
CR	Broca's	30.19	26.42	1.89	0.00	15.09	24.53	1.89	100
JM	Broca's	21.43	25.00	10.71	3.57	7.14	28.57	3.57	100
IE	conduction	27.08	27.08	0.00	4.17	12.50	29.17	0.00	100
PW	conduction	27.27	0.00	0.00	0.00	45.45	27.27	0.00	100
FC	anomic	52.38	33.33	9.52	0.00	4.76	0.00	0.00	100
HJ	anomic	27.27	36.36	4.55	0.00	11.36	20.45	0.00	100
HL	anomic	25.00	25.00	0.00	0.00	50.00	0.00	0.00	100

Table 5-6: Error incidence as a percentage of the total number of errors according to Mackenzie's error classification (1982).

Key for Table 5-5 and Table 5-6: Env. Replace. - Environmental replacement; R by R - Replacement by Reduction.

5.1.5.1 Incidence of error type

The total number of errors for Wood's classification is inflated (range 13 to 70) compared to Mackenzie (range 11 to 53, see Table 5-3 and Table 5-5 respectively) because the scoring of errors in more than one category was allowed for in the former. For example, Mackenzie would mark "tick" → [kit] as metathesis only. For Wood this would be marked in three separate places: metathesis; [k] for /t/ substitution; and [t] for /k/ substitution. To allow comparison of the two classification schemes environmental and non environmental categories (Wood 1996) were collapsed. Only substitutions, distortions, additions and omissions will be considered in this section. These are summarized in Table 5-7, Table 5-8, Table 5-9 and Table 5-10. Whilst some of the percentage of error types maybe regarded as comparable for the two different classification schemes (for example, MU substitution: Wood 64.91% (Table 5-8); Mackenzie 68.75% (Table 5-10)); others were widely different (for example BA substitution: Wood 36.67% (Table 5-8); Mackenzie 14.81% (Table 5-10)). This is perhaps better indicated in the table summarizing the most common errors and corresponding graphs (Table 5-11, Graph 5-1 & Graph 5-2).

Subject	Diagnosis	Substitution	Distortion	Addition	Omission	Total
FM	Broca's/AOS	15	26	15	5	61
MU	Broca's/AOS	37	9	9	2	57
BA	Broca's	11	11	8	0	30
CR	Broca's	18	29	11	5	63
JM	Broca's	18	16	3	2	39
IE	conduction	33	10	10	2	55
PW	conduction	4	2	6	0	12
FC	anomic	11	6	4	4	25
HJ	anomic	15	17	10	2	44
HL	anomic	4	3	8	0	15

Table 5-7: Incidence of substitutions, distortions, additions and omissions irrespective of environmental influences (Wood, 1996).

Subject	Diagnosis	Substitution	Distortion	Addition	Omission	Total
FM	Broca's/AOS	24.59	42.62	24.59	8.20	100.00
MU	Broca's/AOS	64.91	15.79	15.79	3.51	100.00
BA	Broca's	36.67	36.67	26.67	0.00	100.00
CR	Broca's	28.57	46.03	17.46	7.94	100.00
JM	Broca's	46.15	41.03	7.69	5.13	100.00
IE	conduction	60.00	18.18	18.18	3.64	100.00
PW	conduction	33.33	16.67	50.00	0.00	100.00
FC	anomic	44.00	24.00	16.00	16.00	100.00
HJ	anomic	34.09	38.64	22.73	4.55	100.00
HL	anomic	26.67	20.00	53.33	0.00	100.00

Table 5-8: Percentage of substitutions, distortions, additions and omissions irrespective of environmental influences (Wood, 1996).

Subject	Diagnosis	Substitution	Distortion	Addition	Omission	Total
FM	Broca's/AOS	8	14	13	2	37
MU	Broca's/AOS	11	1	3	1	16
BA	Broca's	4	17	6	0	27
CR	Broca's	16	14	8	1	39
JM	Broca's	6	7	2	3	18
IE	conduction	13	13	6	0	32
PW	conduction	3	0	5	0	8
FC	anomic	11	7	1	2	21
HJ	anomic	12	16	5	2	35
HL	anomic	4	4	8	0	16

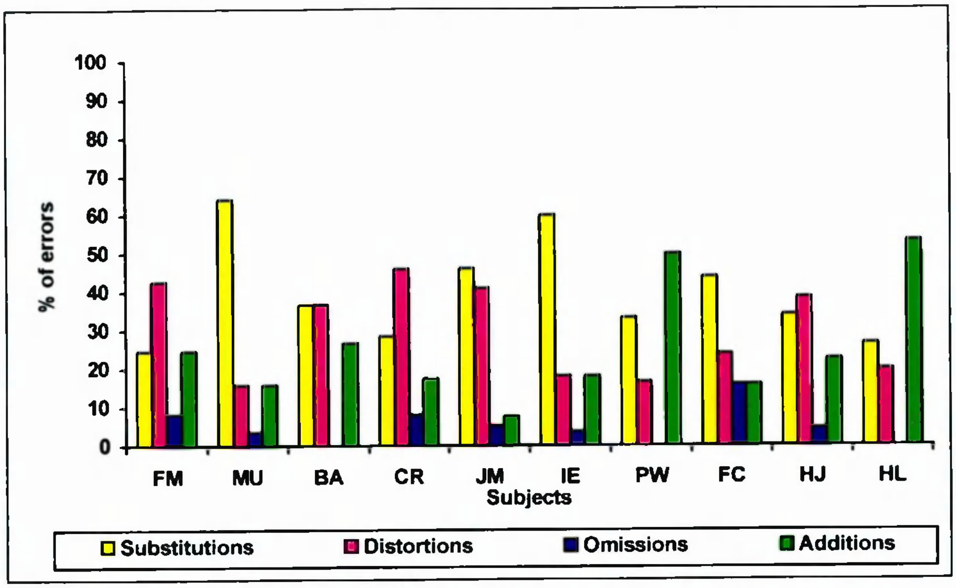
Table 5-9: Number of substitutions, distortions, additions and omissions according to the classification scheme of Mackenzie (1982).

Subject	Diagnosis	Substitution	Distortion	Addition	Omission	Total
FM	Broca's/AOS	21.62	37.84	35.14	5.41	100
MU	Broca's/AOS	68.75	6.25	18.75	6.25	100
BA	Broca's	14.81	62.96	22.22	0.00	100
CR	Broca's	41.03	35.90	20.51	2.56	100
JM	Broca's	33.33	38.89	11.11	16.67	100
IE	conduction	40.63	40.63	18.75	0.00	100
PW	conduction	37.50	0.00	62.50	0.00	100
FC	anomic	52.38	33.33	4.76	9.52	100
HJ	anomic	34.29	45.71	14.29	5.71	100
HL	anomic	25.00	25.00	50.00	0.00	100

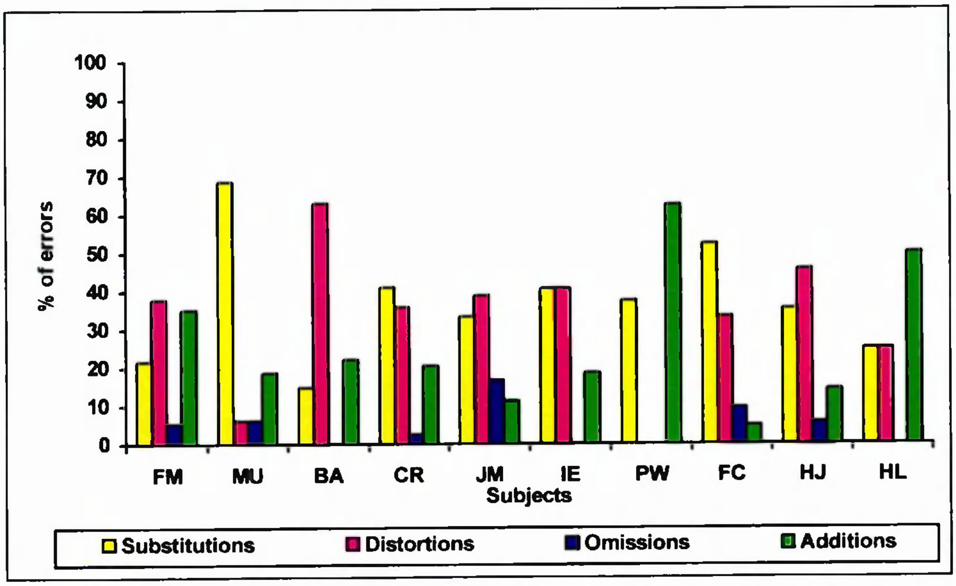
Table 5-10: Percentage of substitutions, distortions, additions and omissions according to the classification scheme of Mackenzie (1982).

Subject	%tage Of Substitutions		%tage Of Distortions		%tage Of Omissions		%tage Of Additions	
	Wood	Mackenzie	Wood	Mackenzie	Wood	Mackenzie	Wood	Mackenzie
FM	24.59	21.62	42.62	37.84	8.20	5.41	24.59	35.14
MU	64.19	68.75	15.79	6.25	3.51	6.25	15.79	18.75
BA	36.67	14.81	36.67	62.96	0.00	0.00	26.67	22.22
CR	28.57	41.03	46.03	35.90	7.94	2.56	17.46	20.51
JM	46.15	33.33	41.03	38.89	5.13	16.67	7.69	11.11
IE	60.00	40.63	18.18	40.63	3.64	0.00	18.18	18.75
PW	33.33	37.50	16.67	0.00	0.00	0.00	50.00	62.50
FC	44.00	52.38	24.00	33.33	16.00	9.52	16.00	4.76
HJ	34.09	34.29	38.64	45.71	4.55	5.71	22.73	14.29
HL	26.67	25.00	20.00	25.00	0.00	0.00	53.33	50.00

Table 5-11: Summary of classification schemes (Wood, 1996 and Mackenzie, 1982) detailing percentage of substitutions, distortions, omissions, and additions.



Graph 5-1: Percentage of error types for each subject using Wood's (1996) classification.



Graph 5-2: Percentage of error types for each subject using Mackenzie's (1982) classification.

Six out of the ten subjects demonstrated the same most common errors irrespective of whether the data was classified using Wood's or Mackenzie's taxonomy (FM distortion; MU substitution; PW addition FC substitution; HJ distortion; HL addition), although the error incidence percentage for Wood and Mackenzie is variable. Four subjects do not share the same error type for the most frequently occurring error. The discrepancies involve substitution versus distortion which are the two error types frequently reported in the literature as characteristic of AOS. The disagreement involves the subjects BA, CR, JM, IE, the first three being Broca's aphasics (without AOS) and the latter a conduction aphasic. Their speech diagnosis and most frequent error type for both methods of classification is given in Table 5-12.

Subject	Speech diagnosis	Wood (1996)	Mackenzie (1982)
BA	Broca's without AOS	Distortion/Substitution (36.67%)	Distortion (62.96%)
CR	Broca's without AOS	Distortion (46.03%)	Substitution (41.03%)
JM	Broca's without AOS	Substitution (46.15%)	Distortion (38.89%)
IE	conduction aphasic	Substitution (60%)	Substitution/Distortion (40.63%)

Table 5-12: Most common error type for BA, CR, JM, and IE according to the classification schemes of Wood (1996) and Mackenzie (1982).

It appears that the choice of classification taxonomy is highly influential with respect to which error type is the most frequently occurring. Whilst it is accepted that this study is limited not only in number of subjects but also in target words, it still highlights the fact that different classification schemes give different results. Therefore we must be cautious when comparing results from different studies since these seem dependent on the methodology chosen.

5.1.5.2 Relationship between speech diagnosis and most common error type

There appeared to be no obvious relationship between the most common type of error and the speech diagnosis for either method of classification for the ten subjects recorded in this investigation. This information is summarized in Table 5-13.

It is recognized that the numbers in this study are very small and therefore it is inappropriate to suggest that they are typical of a larger population. However, the results above remind us that the disagreement between researchers on the most common error type for specified aphasic syndromes is very real. From Wood (1996) (Table 5-13) it can be seen that for each syndrome (Broca's with AOS, Broca's without AOS, conduction, and anomic) not one error type is more prevalent than the others. Substitutions and distortions are clearly more frequent than additions for patients with acquired aphasia and all are more common than errors of omission which were seen in 3 subjects (Wood) and 4 subjects (Mackenzie) (see Table 5-11). More studies are necessary using comparable methodologies if we want to discover whether or not certain error types are more frequent than others in different aphasias. In particular, we must consider subject selection in more detail (classification of subjects, time since onset, and severity), the type of data (e.g. words versus sentences, elicited versus spontaneous speech) and the error classification scheme. We cannot begin to compare different studies if they are not testing the same phenomena.

Speech diagnosis	Number of subjects	Most common error type by subject	
		Wood (1996)	Mackenzie (1982)
Broca's with AOS	2	Substitution (MU) Distortion (FM)	Substitution (MU) Distortion (FM)
Broca's without AOS	3	Substitution (JM) Distortion (CR) Equal substitution / distortion (BA)	Distortion (BA, JM) Substitution (CR)
conduction	2	Substitution (IE) Addition (PW)	Substitution / Distortion(IE) Addition (PW)
anomic	3	Substitution (FC) Distortion (HJ) Addition (HL)	Substitution (FC) Distortion (HJ) Addition (HL)

Table 5-13: Most common error type for each subject. Subjects are grouped according to aphasia classification.

5.1.5.3 Substitutions

The frequency of environmental versus non environmental substitution errors appeared to be subject specific and not dependent on the aphasia syndrome (see Table 5-3 and Table 5-4). For example, whilst CR and JM, both classified as Broca's aphasics without AOS, produced 8 environmental substitutions compared to 10 non environmental substitutions, BA, also classified as a Broca's aphasic without AOS produced only environmental substitutions. FM who was diagnosed as a Broca's aphasic with AOS produced twice the number of non environmental substitutions (10) to environmental (5). In contrast, MU who has the same speech diagnosis as FM, produced almost an equal number of environmental compared to non environmental substitutions (17 compared to 20 respectively). Anomic and conduction aphasics demonstrated similar intra-group discrepancies. Those individuals who did not demonstrate environmental substitutions also produced zero or fewer distortions and additions which were influenced by other phonemes in the word than non environmental errors.

Error matrices were constructed for the different syndromes (Table 5-20, Table 5-21, Table 5-22, and Table 5-23) and one for all the subjects (Table 5-19). These display the phoneme target across the horizontal axis and the phonetic realization on the vertical. At the bottom of each matrix the total number of errors for each phoneme, the total number of possible occurrences for each phoneme (singletons only) and what percentage of each phoneme was perceived as a substitution is given.

It is considered normal to substitute [n] for /ŋ/ in certain environments, for example /tıklıŋ/ → [tıklın]. Therefore any appropriate substitutions of this kind were not recorded on the error substitution matrices (Table 5-19, Table 5-20, Table 5-21, Table 5-22 and Table 5-23). Since some phonemes occurred more frequently than others in the speech sample we will concern ourselves only with the percentage of phonemes where a substitution was perceived and not the actual incidence of errors.

From Table 5-19 which summarizes all 10 aphasics we can see that the post alveolar fricative /ʃ/ was the most frequently substituted phoneme (28.1%), followed by /g/ (27.6%) and then /tʃ/ (23.8%). The majority of substitutions for /ʃ/ (25/34 = 73.5%) involved placement of the tongue rather than manner of production (e.g. /ʃ/ → [s]). This was not true for the target /g/ where only 50% (4/8) of perceived substitutions were a result of placement alone. For target /tʃ/ 53.3% of substitutions (8/15) were a simplification of the target (e.g. /tʃ/ → [ʃ]). The remaining errors were scattered showing no tendency towards any one phoneme. Table 5-14 below summarizes the substitution data further by collapsing voiced/voiceless categories for bilabial, alveolar, and velar plosives, all fricatives and affricates plus /m/ and /n/. This enables analysis of substitution by place without considering laryngeal activity.

All subjects								
	Plosives			Fricatives			Affricates	Nasal
	B	A	V	Ld	A	Pa		
Errors	2	20	69	2	7	34	15	1
Total	143	363	371	34	77	120	63	95
%tage	1.4	5.5	18.6	5.8	9.1	28.1	23.8	1.1

Table 5-14: Incidence of substitution errors as a function of place of articulation for all subjects. The total number of possible productions for each type of articulation is given and the percentage of errors recorded for each manner of articulation according to place. Key: B = bilabial, A = alveolar, V = velar, Ld = labiodental, Pa = post alveolar.

Post alveolar fricatives continue to be the most frequently substituted phoneme (28.1%) followed by affricates (23.8%) then velars (18.6%). The drop in substituted velars is a direct result of a proportionally less number of voiceless to voiced velar plosives being substituted by another phoneme. However, the total number of possible occurrences of the target phonemes vary (post alveolar fricatives = 121, affricates = 64, and velars = 371).

The least frequently substituted phonemes for the 10 aphasics as a group were alveolar approximants /r/ (0%), lateral alveolar approximants /l/ (0%), nasals /m/ and /n/ (1.1%) and bilabial plosives /b/ and /p/ (1.4%).

Aphasic patients are often classified according to the symptoms they manifest, both speech and language. Patients are diagnosed with AOS because they demonstrate certain speech characteristics, for example, groping articulatory behaviour, particular difficulty with initial consonants, and an increase in the number of errors with increasing word complexity (Darley et al., 1975). Many researchers believe that Broca's aphasics and apraxia of speech are the synonymous and therefore do not distinguish between the two disorders. However, it is unlikely that anyone would want to claim that conduction aphasics or anomic aphasics share the same speech production errors as Broca's or apraxic speakers. Each of the aphasic syndromes' substitution error patterns will now be considered individually in greater detail to establish if indeed patients of different syndromes manifest different patterns in speech production errors.

5.1.5.4 Broca's aphasics with AOS

This group consisted of two subjects. Their substitution error patterns will be discussed and then compared to those diagnosed as Broca's aphasics without AOS. Table 5-20 is the error matrix for the 2 Broca's aphasics with AOS. The "% of errors" row indicates that both /z/ and /g/ target phonemes were substituted 100% of the time. However, there was only one occurrence of /z/ for this group due to productions that were either distorted or unrecognizable responses (see definition Section 5.1.4) which are not under discussion here. Therefore the percentage of substitutions may be misleading. For /g/, 75% of errors involved place of articulation, the voicing being maintained (/g/ → [d]) and 25% of errors involved voicing only (/g/ → /k/). The single error for target /z/ also involved a change of one distinctive feature, voicing. Errors of voicing were considered characteristic of the disorder AOS by Kent and Rosenbek (1983). This is certainly not an overwhelming characteristic of the data from this study. Two out of a possible seven voiced bilabial plosives were devoiced (22.2%), one out of sixteen alveolar plosives (11.1%), and one out of four velar plosives (25%). Therefore overall 13.3% of voiced plosives were devoiced. Errors in the reverse, that is voicing of voiceless plosives, were even fewer (0/10 voiceless bilabial plosives, 1/35 voiceless alveolar plosives, and 1/60 voiceless velar plosives, 2.1% in total).

Other phonemes that were frequently substituted in this group were /ʃ/ (52.9%) and /tʃ/ (37.5%). Substitutions involved either one or two distinctive features which Darley et al. (1975) consider typical of those patients with AOS. Only one of the substitution errors for the phonemes /ʃ/ and /tʃ/ involved voicing. The others were all characterized by either place, /ʃ/ → [s], manner, /tʃ/ → [ʃ], /ʃ/ → [tʃ], or both place and manner /tʃ/ → [t].

Table 5-15 summarizes the substitution data according to place and manner of articulation for subjects diagnosed as Broca's with AOS.

Broca's aphasics with apraxia of speech								
	Plosives			Fricatives			Affricates	Nasal
	B	A	V	Ld	A	Pa		
Errors	2	4	22	2	3	9	3	1
Total	19	52	64	5	12	17	8	18
%tage	10.5	7.7	34.4	40	25	52.9	37.5	5.6

Table 5-15: Incidence of substitution errors as a function of place of articulation for subjects diagnosed as Broca's aphasics with accompanying AOS. The total number of possible productions for each type of articulation is given and

the percentage of errors recorded for each manner of articulation according to place. Key: B = bilabial, A = alveolar, V = velar, Ld = labiodental, Pa = post alveolar.

All places of articulation for plosives and fricatives were affected as were affricates and nasals. For plosives, velars were the most frequently substituted sound which is the same as the Broca's without AOS (see Table 5-16). However, contrary to this group, the subjects with Broca's aphasia and AOS substituted bilabials more often (10.5%) than alveolars (7.7%). For fricatives, post alveolar was the place of articulation most frequently substituted which compares to the Broca's aphasics without AOS (see Table 5-16). However, unlike this group, those with Broca's aphasia and AOS experienced difficulty with labiodental fricatives with 40% substitution error being recorded.

With the exception of alveolar plosives, those subjects described as Broca's aphasics with AOS produced a greater overall percentage of errors than those diagnosed as Broca's without AOS. They also substituted certain classes of sounds which were error free for the Broca's aphasics without AOS (bilabial plosives, labiodental fricatives, and nasals).

5.1.5.5 *Broca's aphasics without AOS*

This group consisted of three subjects who were not considered to be apraxic. From Table 5-21 it can be seen that /tʃ/ was the phoneme most frequently substituted (35%) followed by /g/ and /w/ (both 25%). Substitutions for /tʃ/ involved both place and manner (/tʃ/ → [ʃ], [p], [t], [f], [w]). Errors for voiced velar plosives always involved voicing (/g/ → [k]) which is said to be characteristic of AOS (Kent and Rosenbek, 1983). Substitution errors for the approximant /w/ involved both place and manner (/w/ → [b], [v]). Voiced plosives were more frequently replaced than voiceless. For example, 6.1% of voiceless alveolar plosives (/t/) compared to 14.3% of its voiced partner /d/ were substituted. Similarly, 11.8% of voiceless velar plosives /k/ were substituted compared to 25% of voiced velar plosives /g/. This was not true of fricatives where all voiced alveolar fricatives /z/ were correctly realized compared to the voiceless alveolar fricative where 4.2% were substituted. The substitution data for Broca's aphasics without AOS is summarized according to place and manner of the target phoneme in Table 5-16. Velars are the most common plosive to be perceived as incorrect (12.7%) followed by alveolars (9.3%). The Broca's aphasics without AOS appeared to have no difficulty with bilabial plosives. For fricatives, post alveolar fricatives are substituted over 4 times more frequently than alveolar fricatives /s, z/. Labiodental fricatives were all correctly produced.

Broca's aphasics without apraxia of speech								
	Plosives			Fricatives			Affricates	Nasal
	B	A	V	Ld	A	Pa		
Errors	0	10	14	0	1	6	7	0
Total	44	108	110	9	27	36	20	31
%tage	0	9.3	12.7	0	3.7	16.7	35	0

Table 5-16: Incidence of substitution errors as a function of place of articulation for subjects diagnosed as Broca's aphasics without apraxia of speech. The total number of possible productions for each type of articulation is given and the percentage of errors recorded for each manner of articulation according to place. Key: B = bilabial, A = alveolar, V = velar, Ld = labiodental, Pa = post alveolar.

5.1.5.6 *Conduction aphasics*

Table 5-22 shows the error matrix for the two conduction aphasics. The voiceless post alveolar fricative /ʃ/ was the most frequently substituted phoneme for this group (44%). Most of the errors (9/11) involved purely place of articulation (/ʃ/ → [s]). The remaining two errors involved place and manner of articulation (/ʃ/ → [t, tʃ]. The velar plosives /g/ and /k/ were the next most frequently substituted phonemes (33.3% and 26% respectively). Most velar plosive errors (20/22) involved one distinctive feature, place of articulation. Voicing errors were infrequent (see Table 5-22).

Conduction aphasics								
	Plosives			Fricatives			Affricates	Nasal
	B	A	V	Ld	A	Pa		
Errors	0	6	22	0	1	11	2	0
Total	30	80	83	8	22	25	13	22
%tage	0	7.5	26.5	0	4.5	44	15.4	0

Table 5-17: Incidence of substitution errors as a function of place of articulation for conduction aphasics. The total number of possible productions for each type of articulation is given and the percentage of errors recorded for each manner of articulation according to place. Key: B = bilabial, A = alveolar, V = velar, Ld = labiodental, Pa = post alveolar.

Table 5-17 summarizes the data according to place and manner of articulation. Similarities between conduction and Broca's aphasics without AOS can be seen. Neither group substituted bilabial plosives, labiodental fricatives or nasals. Velar plosives were more frequently substituted than alveolars as were post alveolar compared to alveolar fricatives. Differences between conduction and Broca's aphasics concern the frequency of the errors with conduction aphasics substituting more velar plosives and post alveolar fricatives but less affricates than the Broca's aphasic.

5.1.5.7 Anomic

The three anomic aphasics made the fewest number of substitution errors as a group compared to the other groups. There were many more phonemes that were error free than Broca's (with or without AOS) and conduction aphasics (see Table 5-23). /ʃ/ was the most frequently substituted phoneme (18.6%). All substitutions for /ʃ/ differed from the target by one distinctive feature involving either placement (/ʃ/ → [s]) or manner (/ʃ/ → [tʃ]). The affricate /tʃ/ was the second most frequently substituted phoneme (13.6%). All substitutions were a simplification of the target, /tʃ/ → [ʃ]. The voiceless velar plosive /k/ was the next most frequently substituted target (10.7%). All substitutions for this phoneme involved one distinctive feature, 9/11 were errors of voicing and 2/11 were place of articulation (/k/ → [t]).

Table 5-18 summarizes the data as before. A similar pattern to the Broca's without AOS and conduction aphasics emerges since there are no errors for bilabial plosives, labiodental fricatives or nasals. Furthermore, velar plosives were more frequently substituted than alveolar plosives and post alveolar fricatives more often than alveolar fricatives.

Anomic aphasics								
	Plosives			Fricatives			Affricates	Nasal
	B	A	V	Ld	A	Pa		
Errors	0	2	11	0	2	8	3	0
Total	48	124	114	12	27	43	22	34
%tage	0	1.6	9.6	0	7.4	18.6	13.6	0

Table 5-18: Incidence of substitution errors as a function of place of articulation for anomic aphasics. The total number of possible productions for each type of articulation is given and the percentage of errors recorded for each manner of articulation according to place. Key: B = bilabial, A = alveolar, V = velar, Ld = labiodental, Pa = post alveolar.

5.1.6 Summary

This section has reviewed three different systems of classification for recording speech sound errors (Blumstein, 1973; Mackenzie, 1982; Miller, 1995). From the evaluation of these an alternative method of classification was proposed. Features felt to be of importance which were not necessarily included in these earlier taxonomies were errors of distortion, marking errors influenced by environmental factors and the ability to record an error in more than one place (e.g. metathesis also recorded appropriately under the category substitution). The taxonomy chosen was simplistic for ease of implementation and following Miller's (1995) criticism that his elaborated taxonomy did not add any additional information.

This new classification scheme is not without criticism. The corpus of material did not adequately sample all phonemes of the English language. However, the use of a specific set of words was felt to be more informative than conversational speech samples since this does not allow the direct comparison of individuals. It also benefits from the inclusion of environmental influences. It may be interesting to include the analysis of aborted attempts and retrials prior to the target in addition to the final attempt. Often the final production was a correct production and therefore previous errors were ignored. But these may provide important information with regards to the speech disorder.

Comparison of the data classified according to Wood (1996) and Mackenzie (1982) highlights that the incidence of errors is highly dependent upon the choice of taxonomy. Whilst six out of the ten subjects demonstrated the same most common errors when the two systems were compared, four out of ten did not. The discrepancies involved errors of substitution and distortion which are the most frequently cited errors in the literature surrounding AOS.

Classification under the newly proposed scheme did not reveal a predominance of one type of error for any one aphasia syndrome. However, the restricted number of subjects may be influential. Fricatives and affricates were the most commonly substituted sounds for all the aphasics investigated. Broca's with AOS, conduction aphasics and anomics all substituted post alveolar fricatives most frequently. For Broca's without AOS this was ranked second in order of substitution frequency. The errors for all the aphasics involved either one or two distinctive features, a phenomenon traditionally considered characteristic of AOS. Surprisingly the Broca's aphasics with AOS had far fewer voicing difficulties than the Broca's aphasics without AOS. Errors of voicing are traditionally considered a diagnostic feature of AOS.

The Broca's without AOS and the conduction aphasics were similar in the sounds which they substituted. They differed in the frequency of substitutions, conduction aphasics substituting fewer sounds than the Broca's without AOS. The anomic aphasics produced the fewest number of substitutions errors although all classes of phonemes (plosives, fricatives, affricates and nasals) were affected as they were for all the other aphasic syndromes.

5.1.7 "Pure" substitutions

The lingual/palatal contacts of a small subset of substitutions were examined to identify how many of these errors were actually "pure" substitutions. The term "pure" is used to refer to those errors where the lingual/palatal contact patterns confirmed the auditory impression. For example where the target word "a key" was heard [ə t^hi] the EPG print-outs were analysed to determine whether contacts had been made which are typical of an alveolar plosive. Only the singleton plosive targets /p,b,t,d,k,g/ occurring in word initial and word final position were examined. Twenty-eight substitutions produced by four aphasics were identified (FM, Broca's with AOS; MU, Broca's with AOS; BA, Broca's without AOS and IE, conduction aphasic). Of the substitutions detected through auditory analysis 26 were target velar plosives (92.8%) and 18 of these were in word initial position (69.2%). The phonetic transcription and the corresponding lingual/palatal contact patterns for target words where a substitution was perceived are detailed in Appendix C.

Analysis of the EPG data revealed that 25% of the perceived substitutions showed lingual/palatal contact patterns which were not detected through auditory analysis. These could be separated into three different types: alveolar contacts detected during the production of a target word final velar heard as a bilabial substitution (target word "shark" heard as [ʃaːɹp] and [tʃaɹp]); four examples of a double alveolar/velar contact pattern during WI alveolar or velar targets; and one instance where a target velar was heard as an alveolar substitution but the EPG contact patterns showed full velar closure typical of a stop gesture with no associated alveolar contacts ("cocktail" heard as [ʌ tʰɔktɛl]). For those examples where alveolar contacts were detected during a perceived bilabial plosive, the lingual/palatal contacts were released prior to the bilabial plosive. Therefore the alveolar release had no acoustic consequence. Where a double alveolar/velar pattern was detected, the gesture which was released second was the phoneme which was detected during auditory analysis. Presumably the gesture which was released first also had no acoustic consequence and is therefore undetected.

From this small subset of data it would appear that substitutions which are detected through auditory-based analysis may not be "pure" substitutions.

Phonetic realization	Phoneme Target																					
	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	l	ɹ	w	h	j
p	70	2			2										1								
b		69		1																	1		
t			218	3	40								2		2								
d			3	125	5	4					1				1			1					
k			6		281	3																	
g			1	3	11	21																	
f				1			32								1								
v																							
θ																							
ð																							
s			1		1		2				62	1	25	1									
z											4	8	1										
ʃ													87		8								
ʒ																							
tʃ			1		2	1					1		6		48								
dʒ															1								
m																	18						
n					1													76					
ŋ																							
l																			90				
ɹ																				161			
w															1						29		
h																						32	
j																							
ERRORS	0	2	12	8	61	8	2	0	0	0	6	1	34	0	15	0	0	1	0	0	1	0	0
TOTAL	70	71	230	133	342	29	34	0	0	0	68	9	121	0	63	0	18	77	90	161	30	32	0
% OF ERRORS	0	2.8	5.2	6.0	17.8	27.6	5.8	0	0	0	8.8	11	28.1	0	23.8	0	0	1.3	0	0	3.3	0	0

Table 5-19: Correct productions and substitution errors - all subjects.

Phonetic realization	Phoneme Target																						
	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	l	ɹ	w	h	j
p	10	2			2																		
b		7																					
t			33	1	14										1								
d				16		3												1					
k			1		42	1																	
g			1		1																		
f							3																
v																							
θ																							
ð																							
s					1		2				9	1	6										
z											2		1										
ʃ													8		2								
ʒ																							
tʃ				1									2		5								
dʒ																							
m																	3						
n																		14					
ŋ																							
l																			8				
ɹ																				27			
w																					2		
h																						4	
j																							
ERRORS	0	2	2	2	18	4	2	0	0	0	2	1	9	0	3	0	0	1	0	0	0	0	0
TOTAL	10	9	34	18	60	4	5	0	0	0	11	1	17	0	8	0	3	15	8	27	2	4	0
% OF ERRORS	0	22.2	5.9	11.1	30	100	40	0	0	0	18.2	100	52.9	0	37.5	0	0	6.7	0	0	0	0	0

Table 5-20: Correct productions and substitution errors - Broca's aphasics with AOS.

Phonetic realization	Phoneme Target																						
	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	l	ɹ	w	h	j
p	22														1								
b		22		1																	1		
t			62		5								1		1								
d			2	36	4																		
k			2		90	2																	
g				3	1	6																	
f				1			9								1								
v																					1		
θ																							
ð																							
s											23		4										
z												3											
ʃ													30		3								
ʒ																							
tʃ					2						1		1		13								
dʒ																							
m																	5						
n				1														26					
ŋ																							
l																			31				
ɹ																				54			
w															1						6		
h																						10	
j																							
ERRORS	0	0	4	6	12	2	0	0	0	0	1	0	6	0	7	0	0	0	0	0	2	0	0
TOTAL	22	22	66	42	102	8	9	0	0	0	24	3	36	0	20	0	5	26	31	54	8	10	0
% OF ERRORS	0	0	6.1	14.3	11.8	25	0	0	0	0	4.2	0	16.7	0	35	0	0	0	0	0	25	0	0

Table 5-21: Correct productions and substitution errors - Broca's aphasics without AOS.

Phonetic realization	Phoneme Target																						
	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	l	ɹ	w	h	j
p	14																						
b		16																					
t			46	2	19								1										
d			1	28	1	1					1				1								
k			2		57																		
g						4																	
f							8																
v																							
θ																							
ð																							
s											17		9		1								
z												4											
ʃ													14										
ʒ																							
tʃ			1			1							1		11								
dʒ																							
m																	4						
n																		18					
ŋ																							
l																			22				
ɹ																				24			
w																					9		
h																						7	
j																							
ERRORS	0	0	4	2	20	2	0	0	0	0	1	0	11	0	2	0	0	0	0	0	0	0	0
TOTAL	14	16	50	30	77	6	8	0	0	0	18	4	25	0	13	0	4	18	22	24	9	7	0
% OF ERRORS	0	0	8	6.7	26	33.3	0	0	0	0	5.6	0	44	0	15.4	0	0	0	0	0	0	0	0

Table 5-22: Correct productions and substitution errors - conduction aphasics.

Phonetic realization	Phoneme Target																						
	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	l	ɹ	w	h	j
p	24																						
b		24																					
t			77		2																		
d				45																			
k			1		92																		
g					9	11																	
f							12																
v																							
θ																							
ð																							
s			1								21		6										
z											2	4											
ʃ													35		3								
ʒ																							
tʃ													2		19								
dʒ																							
m																	6						
n																		28					
ŋ																							
l																			29				
ɹ																			2	56			
w																					12		
h																						11	
j																							
ERRORS	0	0	2	0	11	0	0	0	0	0	2	0	8	0	3	0	0	0	2	0	0	0	0
TOTAL	24	24	79	45	103	11	12	0	0	0	23	4	43	0	22	0	6	28	31	56	12	11	0
% OF ERRORS	0	0	2.5	0	10.7	0	0	0	0	0	8.7	0	18.6	0	13.6	0	0	0	6.5	0	0	0	0

Table 5-23: Correct productions and substitution errors - anomic aphasics.

5.1.8 Summary of results

The following is a summary of the main points arising from analysis and development of classification schemes for the perceptual analysis of aphasic speech and a study of substitution errors perceived through auditory-based analysis.

1. The type of classification scheme which is adopted for perceptual analysis affects the percentage of error types recorded (e.g. substitutions, distortions, etc.).

   Using the new classification scheme proposed in this section (Wood, 1996):

2. Errors of voicing were infrequent for Broca's aphasics with AOS. Kent and Rosenbek (1983) suggest that this is a characteristic of AOS. In this investigation, Broca's without AOS demonstrated more errors of voicing than those diagnosed with AOS.
3. Broca's aphasics with AOS demonstrated substitution errors for all places of articulation.
4. Broca's aphasics without AOS, conduction aphasics and anomic aphasics did not substitute bilabial plosives, labiodental fricatives or nasals. Therefore some places of articulation were error free.
5. /ʃ/ was the most frequently substituted sound for conduction and anomic aphasics and was also frequently substituted in the speech of Broca's aphasics without AOS.
6. Velar plosives were more frequently substituted than alveolar plosives for all aphasia types.
7. Post alveolar fricatives were more frequently substituted than alveolar fricatives for all aphasia types.
8. Errors of substitution for all aphasics involved either one or two distinctive features.
9. Broca's aphasics without AOS and conduction aphasics showed similar patterns of substitution. Differences arose in the percentage of errors recorded. Broca's without AOS substituted more alveolar plosives and affricates than conduction aphasics but fewer fricatives.
10. 75% of substitutions detected through auditory-based analysis were "pure" substitutions. The remaining 25% involved abnormal lingual/palatal contacts which were only detected on analysis of the EPG data.

Chapter 6

6. Results 2: An Instrumental Analysis Of Variability And Sequencing

6.1 Variability

This section looks at the variability of speech produced by both aphasic and normal speakers. Two main questions will be addressed:

1. What constitutes normal variability?
2. Are the aphasic speakers more variable than normal speakers?

Munhall (1982), in his chapter entitled "Articulatory Variability", questions whether normal variability has ever been quantified. He states "comparisons of variability between clinical and normal populations are frequently made without the aid of good normative data" (p.64). Comparisons frequently involve a single normal speaker. This is typical of research into the speech of apraxic speakers (Itoh and Sasanuma, 1984; Kent and Rosenbek, 1983; Weismer et al., 1995). These studies have often reported that the speech of these patients is more variable than normal speakers but the data set that they are compared to is too restrictive to be able to make such claims with any degree of confidence. Therefore one of the aims of this section is to start to quantify the variability of normal speakers and to use this as a means of comparison for the aphasic speakers. In doing this it is hoped to examine whether pathological speech has another source of variation outside that which is present in normal speakers.

To achieve these aims we need to look at both within subject and between subject variability. This section concerns the data collected from the repetition task, specifically production of the words, "deer" and "kitkat" which were each produced ten times by all control subjects and by nine of the aphasic speakers (not BA). Productions which were considered to be spatially typical for the aphasic speakers and therefore classified as correct were subjected to various durational measures. These were compared to identical measures from the control subjects. Spatial variability and coarticulation were also assessed from analysis of the EPG data.

Measures which will be made in this section are:

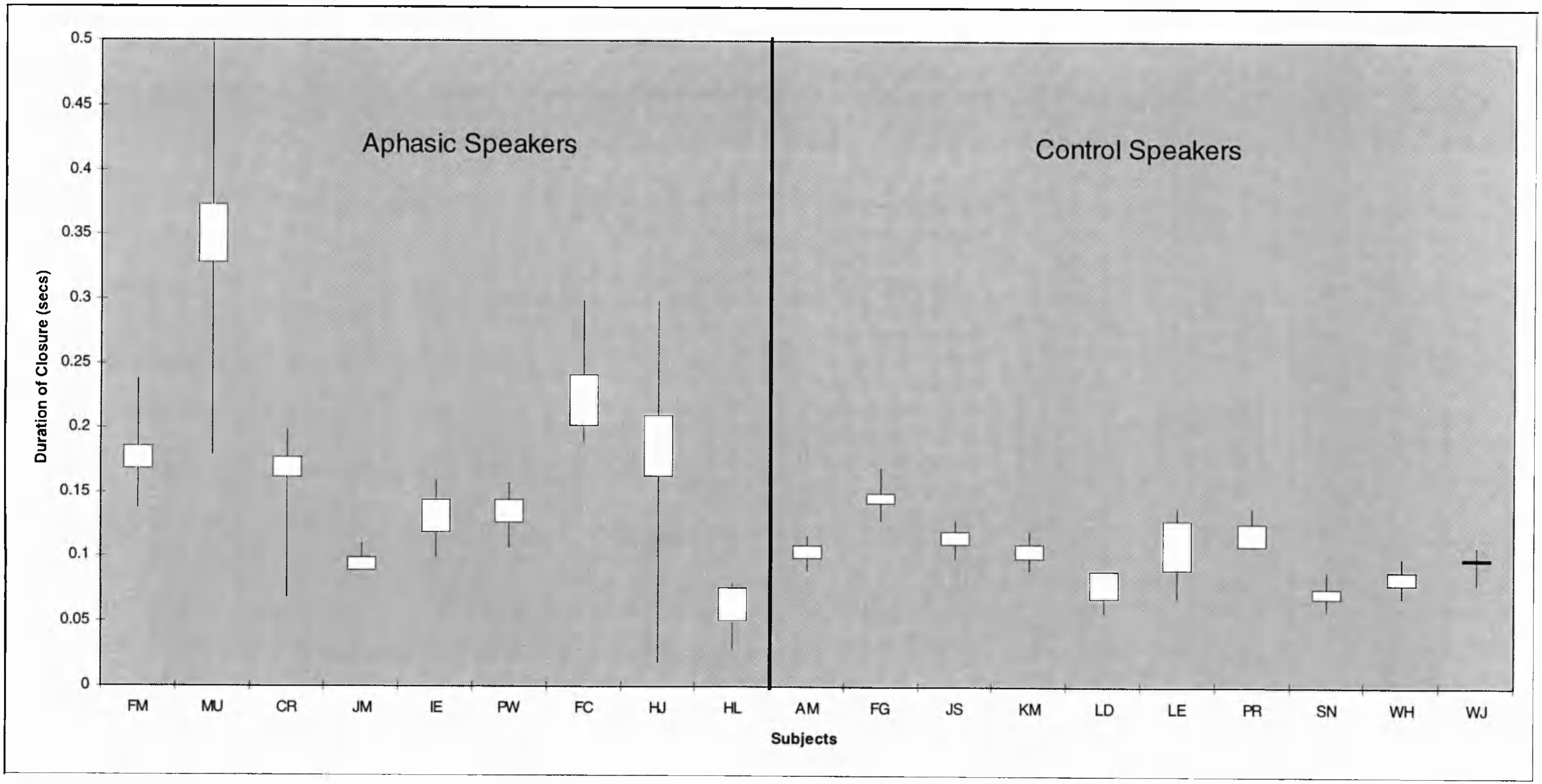
1. Duration of the /d/ closure in "deer".
2. Duration of the /d/ closure in "deer" as a proportion of the whole word.
3. Spatial variability of the /d/ closure.
4. Duration of the /k/ closure in "kitkat".
5. Spatial variability of the /k/ closure.

6.1.1 Duration of the /d/ closure in "deer"

Duration of the /d/ closure was measured from the EPG trace and taken from the first frame of full closure for the alveolar plosive to the last frame of full closure. The time period between each frame is 10 milliseconds (1/100 of a second).

Graph 6-1 shows the range of measures over 10 repetitions for all control and 9 aphasic subjects. The white boxes indicate the interquartile range, the vertical lines the maximum and minimum durations for /d/ closure (for data see Appendix D). What is immediately apparent is that the durations are generally higher for the aphasic subjects and five out of ten (FM, MU, CR, FC, and HJ) show a greater range of distribution. Scatterplots for the 10 control subjects and the 9 aphasic subjects were drawn to capture the variability of durations over the 10 repetitions (see Figure 6-1 for aphasic speakers and Figure 6-2 for control speakers).

These highlight differences in duration from one repetition to the next and in particular the extreme values produced by each subject. Figure 6-2 indicates that the 10 values for the control speakers generally fall along a relatively straight line (with the exception of repetition 10 for JS) indicating consistency of duration. Furthermore, all the values fall around 0.1 seconds. In contrast, the values plotted in Figure 6-1 are clearly less consistent for all subjects except JM and HL. In addition the durations are greater for those subjects who show less consistency in their productions.



Graph 6-1: A box and whisker graph showing the interquartile range (box) and the minimum and maximum duration of /d/ closure over 10 repetitions of the word "deer" for 9 aphasic speakers (FM, MU, CR,JM, IE, PW, FC, HJ and HL) and 10 control subjects (AM, FG, JS, KM, LD, LE, PR, SN, WH, and WJ).

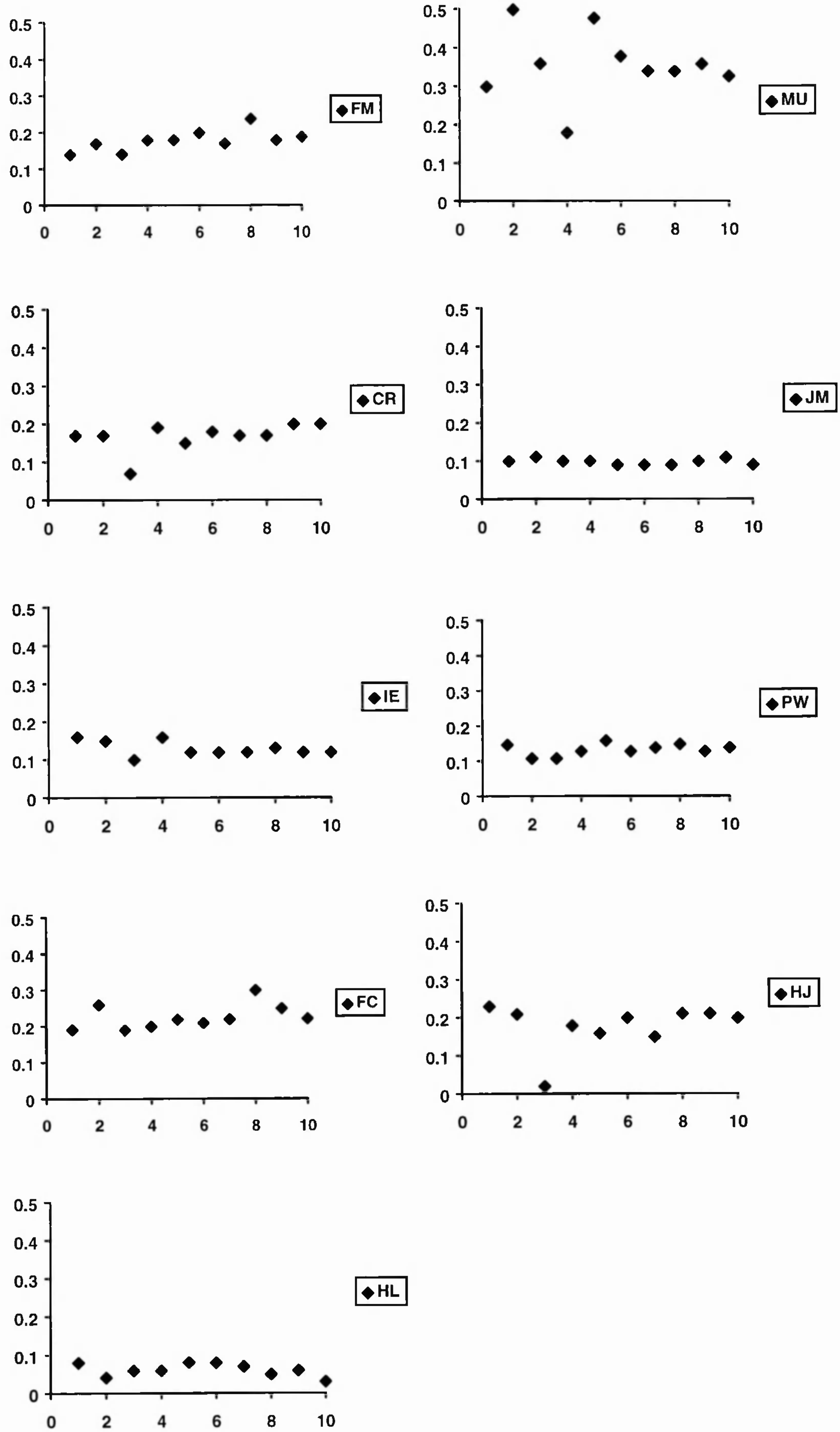


Figure 6-1: Scatterplots detailing variability of duration for /d/ closure in "deer" for aphasic subjects. X axis represents the number of repetitions, Y axis represents the time in seconds.

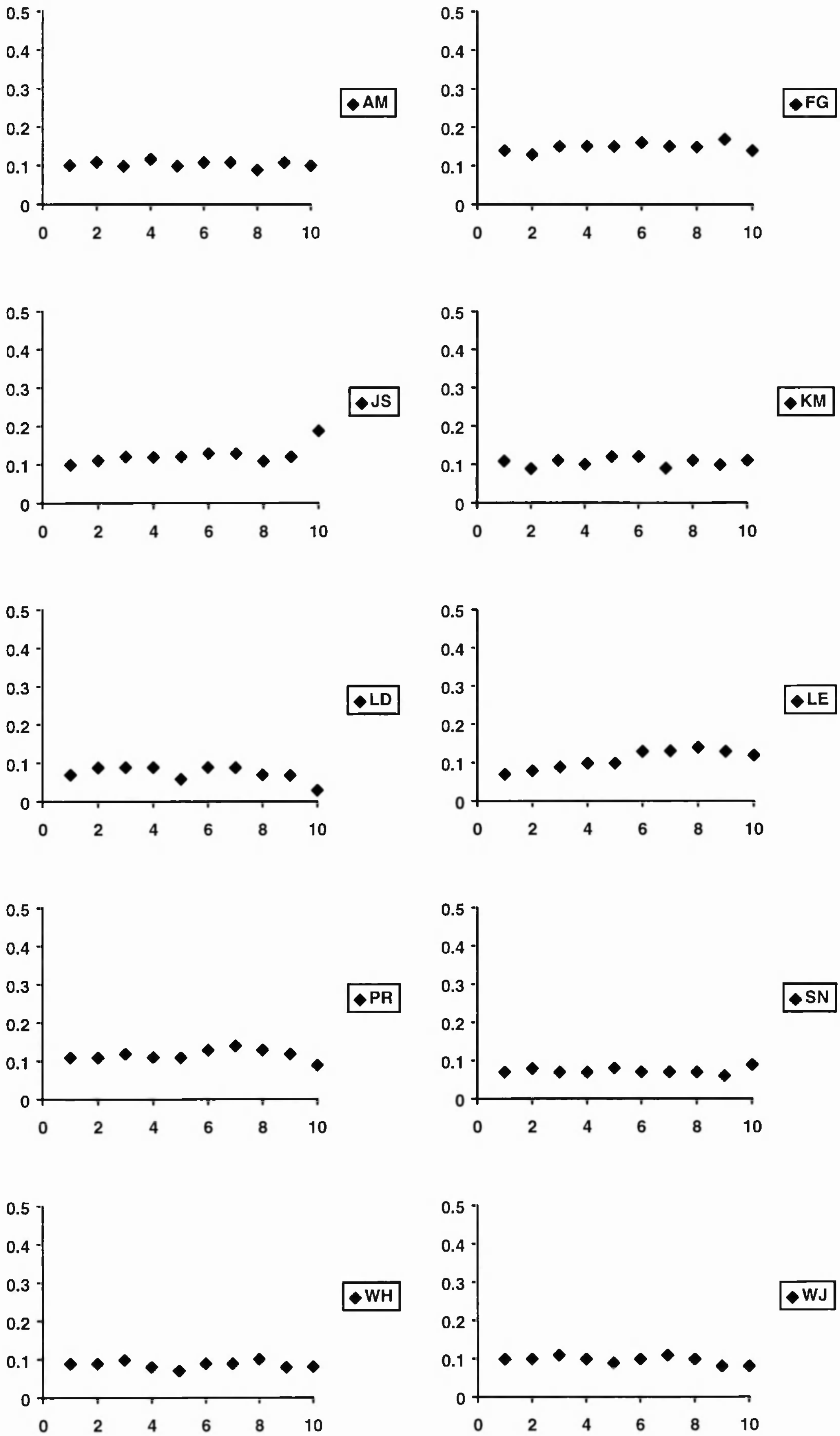


Figure 6-2: Scatterplots detailing variability of duration for /d/ closure in "deer" for control subjects. X axis represents the number of repetitions, Y axis represents the time in seconds.

A test of variance was conducted for each aphasic subject which compared the variability across the ten repetitions with ten repetitions produced by ten control subjects (100 values). The Null hypothesis (H_0) states that the standard deviation of group 1 (aphasic speakers) is equal to the standard deviation of group 2 (control speakers). The Alternative Hypothesis (H_1) states that the standard deviations of groups 1 and 2 are not equal.

Null hypothesis (H_0): $\sigma_1^2 = \sigma_2^2$

Alternative hypothesis: (H_1): $\sigma_1^2 \neq \sigma_2^2$

The following equation was used to calculate F values for each subject (Woods, Fletcher and Hughes, 1986):

$$F = \frac{S_1^2}{S_2^2} \quad \frac{(\text{standard deviation of group 1})^2}{(\text{standard deviation of group 2})^2}$$

Critical values for V1: 9 (n-1); V2: 99 (n-1): F = 1.97 for $\alpha = 0.05$.

The calculated F values for each subject can be seen in Table 6-1 (details of the calculations can be found in Appendix D).

Subject	Speech Diagnosis	F value	Null Hypothesis $\sigma_1^2 = \sigma_2^2$
FM	Broca's with AOS	1.683	cannot reject
MU	Broca's with AOS	16.17	reject
CR	Broca's without AOS	2.746	reject
JM	Broca's without AOS	0.130	cannot reject
IE	conduction	0.802	cannot reject
PW	conduction	0.552	cannot reject
FC	anomic	2.426	reject
HJ	anomic	7.431	reject
HL	anomic	0.606	cannot reject

Table 6-1: F values calculated by the test of variance for the duration of /d/ in "deer" for aphasic speakers. Critical value for ∝= 0.05 is F = 1.97. Rejection of the Null hypothesis is indicated where appropriate.

The null hypothesis ($\sigma_1^2 = \sigma_2^2$) could be rejected (95% confidence level) for four out of the ten aphasic speakers (MU, CR, FC and HJ). Therefore these subjects produced ten repetitions of the word "deer" where the duration of the phoneme /d/ was statistically more variable than the ten repetitions for all control subjects. Surprisingly, these patients were diagnosed as Broca's with AOS, Broca's with AOS, anomic and anomic respectively. Whilst increased variability is considered a feature of AOS (Darley et al., 1975) it is not traditionally associated with anomic aphasics.

6.1.2 Duration of the /d/ closure in "deer" as a proportion of the whole word

This measurement was calculated to see whether increased duration of the stop closure was due to a slower speech rate. Duration of the whole word was calculated from the EPG contact patterns and associated EPG waveform. The starting point was taken as the first frame of complete closure for the alveolar plosive /d/. Therefore the approach phase was ignored. The end of the word was measured from the acoustic waveform as indicated by the end of regular glottal pulsing for the vowel. Before comparing the proportion of the /d/ closure in relation to the whole word for each subject, a test of variance was performed for the duration of the whole word. The ten repetitions for each aphasic subject were compared to the ten repetitions produced by ten control subjects. Details of the statistics can be found in Appendix D. The calculated F values for each subject are given in Table 6-2.

Subject	Speech Diagnosis	F value	Null Hypothesis $\sigma_1^2 = \sigma_2^2$
FM	Broca's with AOS	0.791	cannot reject
MU	Broca's with AOS	2.589	reject
CR	Broca's without AOS	1.203	cannot reject
JM	Broca's without AOS	1.478	cannot reject
IE	conduction	0.372	cannot reject
PW	conduction	0.104	cannot reject
FC	anomic	0.006	cannot reject
HJ	anomic	0.182	cannot reject
HL	anomic	0.332	cannot reject

Table 6-2: F values calculated by the test of variance for duration of the word "deer" for aphasic speakers. Critical value for $\propto = 0.05$ is $F = 1.97$. Rejection of the Null hypothesis is indicated where appropriate.

Only one subject, MU, diagnosed as a Broca's aphasic with AOS, produced ten repetitions which were statistically more variable in their durations than the control subjects (5% confidence interval). This is perhaps unsurprising if we accept the view that apraxic speakers are characteristically more variable in their productions than normal speakers since MU was diagnosed with AOS. However, FM, also diagnosed as Broca's with AOS, did not produce words which were statistically more variable in duration.

The duration of the stop closure as a proportion (p) of the whole word was calculated for all repetitions for control and aphasic subjects. A test comparing the proportions over ten repetitions from each individual aphasic to ten repetitions by ten control speakers (total 100 values) was conducted. The Null hypotheses (H_0) states that the proportion calculated for group 1 (value from individual aphasic speaker) is equal to the proportion calculated for group 2 (all control speakers). The Alternative hypothesis (H_1) states that these two values are not equal.

Null hypothesis (H_0): $p_1 = p_2$

Alternative hypothesis (H_1): $p_1 \neq p_2$

The following equation was used to calculate Z scores for each aphasic speaker (Woods et al., 1986). When the H_0 is true Z will have a standard normal distribution[2].

$$Z = \frac{|\hat{p}_1 - \hat{p}_2| - \frac{1}{2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}{\sqrt{\bar{p}(1-\bar{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where n_1 and n_2 are the sample sizes, $\hat{p}_1$ is the mean durational proportion of the /d/ closure to the whole word for one aphasic subject over 10 repetitions, and $\hat{p}_2$ is the mean durational proportion of the /d/ closure for all control subjects over 10 repetitions. $\hat{p}_1 - \hat{p}_2$ is the absolute magnitude of the difference between $\hat{p}_1$ and $\hat{p}_2$ and is always a positive value. The Z scores are given in Table 6-3, and calculations can be found in

[2] Woods et al. (1986) state that "it is always the normal distribution that is referred to when testing for differences between two simple proportions - never the t-distribution" (p.183).

Appendix D. Since it is a two tailed test, the absolute values were taken for comparison with the critical values.

Subject	Speech Diagnosis	Z score	Null Hypothesis $p_1 = p_2$
FM	Broca's with AOS	0.168	cannot reject
MU	Broca's with AOS	1.376	cannot reject
CR	Broca's without AOS	-0.386	cannot reject
JM	Broca's without AOS	0.185	cannot reject
IE	conduction	-2.575	reject
PW	conduction	0.504	cannot reject
FC	anomic	0.979	cannot reject
HJ	anomic	-0.127	cannot reject
HL	anomic	0.399	cannot reject

Table 6-3: Z values calculated by the test of proportions. Critical value for $\propto$ = 0.05 for two tailed test is Z = 1.96.

Calculation of the Z values indicated that the null hypothesis could be rejected at the 5% confidence level for only one aphasic, IE, diagnosed with conduction aphasia. Therefore, the proportion of the stop closure in relation to the whole word produced by IE was statistically different to the normal subjects. What is interesting is that whilst MU was more variable in the duration of the word "deer" the proportion of the /d/ closure in relation to the duration of the entire word was not statistically different.

6.1.3 Spatial variability of the /d/ closure

The variability index (VI) (Farnetani and Provaglio, 1991) was used to assess the variability of lingual/palatal contact patterns over 10 repetitions of the word "deer" (see Section 3.4.3 for details). Table 6-4 gives the VI values for the normal and the aphasic.

Aphasic	Variability Index (VI)	Control	Variability Index (VI)
FM	2.58	AM	2.58
MU	2.58	FG	3.55
CR	6.61	JS	3.06
JM	6.29	KM	6.77
IE	7.26	LD	10.65
PW	4.19	LE	6.61
FC	2.26	PR	1.45
HJ	12.42	SN	1.45
HL	2.90	WH	2.42
		WJ	1.45
mean	5.23	mean	4.00
standard deviation	3.32	standard deviation	3.05

Table 6-4: Absolute variability calculated by the VI (Farnetani and Provaglio, 1991) for aphasic and control subjects.

The standard deviations indicate a similar range of values for both groups of speakers. Aphasic and control subjects have one value which seems to be unusually higher than the others (aphasic group, HJ: 12.42; control group, LD: 10.65) but the pattern of distribution of these scores is similar for both. Three subjects in the control group recorded the lowest score, 1.45. The lowest value for the aphasic group is 2.26 (FC). A test of variance was conducted to compare the scores calculated by the VI from the two groups. H_0 and H_1 are the same as Section 6.1.1.

Null hypothesis (H_0): $\sigma_1^2 = \sigma_2^2$

Alternative hypothesis: (H_1): $\sigma_1^2 \neq \sigma_2^2$

Critical F values for V1: 89; V2: 99 (nearest in statistical table 100:100):

F = 1.483 for $\alpha = 0.05$

$$F = \frac{S_1^2}{S_2^2} \quad \frac{(\text{standard deviation of group 1})^2}{(\text{standard deviation of group 2})^2} \qquad F = \frac{3.32^2}{3.05^2} = 1.18$$

The null hypothesis cannot be rejected at the 5% confidence level so there is no statistically significant difference between the standard deviations of both groups of speakers.

The EPG frame for the point of maximum closure for /d/ in "deer" is given for each speaker in Figure 6-3 (aphasic speakers) and Figure 6-4 (control speakers). These diagrams highlight the contacts made over ten successive repetitions. Each square represents a single electrode, the shading indicates the number of times each electrode was contacted over 10 repetitions as a percentage. The number in each square is the actual number of times an electrode was contacted.

Common to both groups of speakers is a characteristic horse shoe shape forming lateral and apical seals for the alveolar stop. It appears that the aphasic speakers as a group have a tendency to make more contact than the control speakers along the lateral margins of the palate. This can be seen in FM, CR, PW, FC, and HJ's productions (Broca's with AOS, Broca's without AOS, conduction aphasic, anomic and anomic respectively). This appears to be a subject specific feature and not related to the aphasic syndrome. Only WH from the control group uses two columns for lateral seal. One aphasic (MU, Broca's with AOS) makes increased contact at the front of the palate. The first three rows are consistently activated over ten repetitions and also much of the fourth. This is not a pattern observed in any of the control speakers. The different degrees of shading for HJ is a reflection of the variability of contacts and includes much of the palate. It is not normal for a speaker to use the more central columns in the palatal and alveolar regions during production of a /d/.

6.1.4 Comparison of temporal and spatial variability

The results from temporal variability and spatial variability were compared to determine if those subjects who demonstrated increased variability on one measure also showed an increase in variability for the other. The null hypothesis, $\sigma_1^2 = \sigma_2^2$, for duration of contacts was rejected for MU, CR, FC, and HJ. Therefore these subjects produced voiced alveolar plosives which were statistically more variable in duration than the control subjects. However, only HJ demonstrated greater spatial variability than the control speakers. The mean VI score for the control group was 4 with a standard deviation of 3.05. The VI values calculated for MU, CR and FC were all within +1 standard deviation of the control mean (MU: 2.58, CR: 6.61, FC: 2.26).

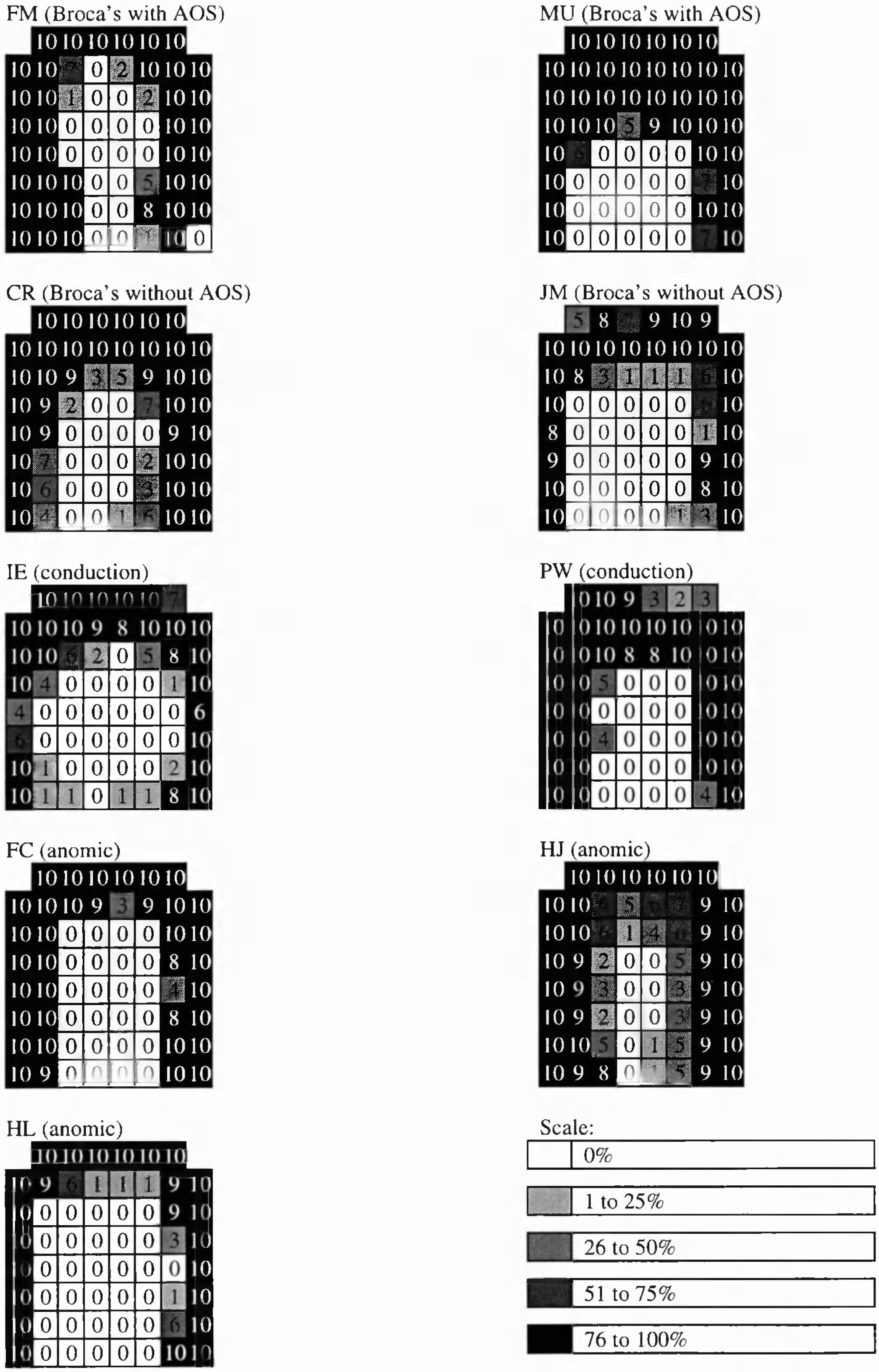


Figure 6-3: Prototypical frame of maximum closure for /d/ over 10 repetitions (aphasic speakers).

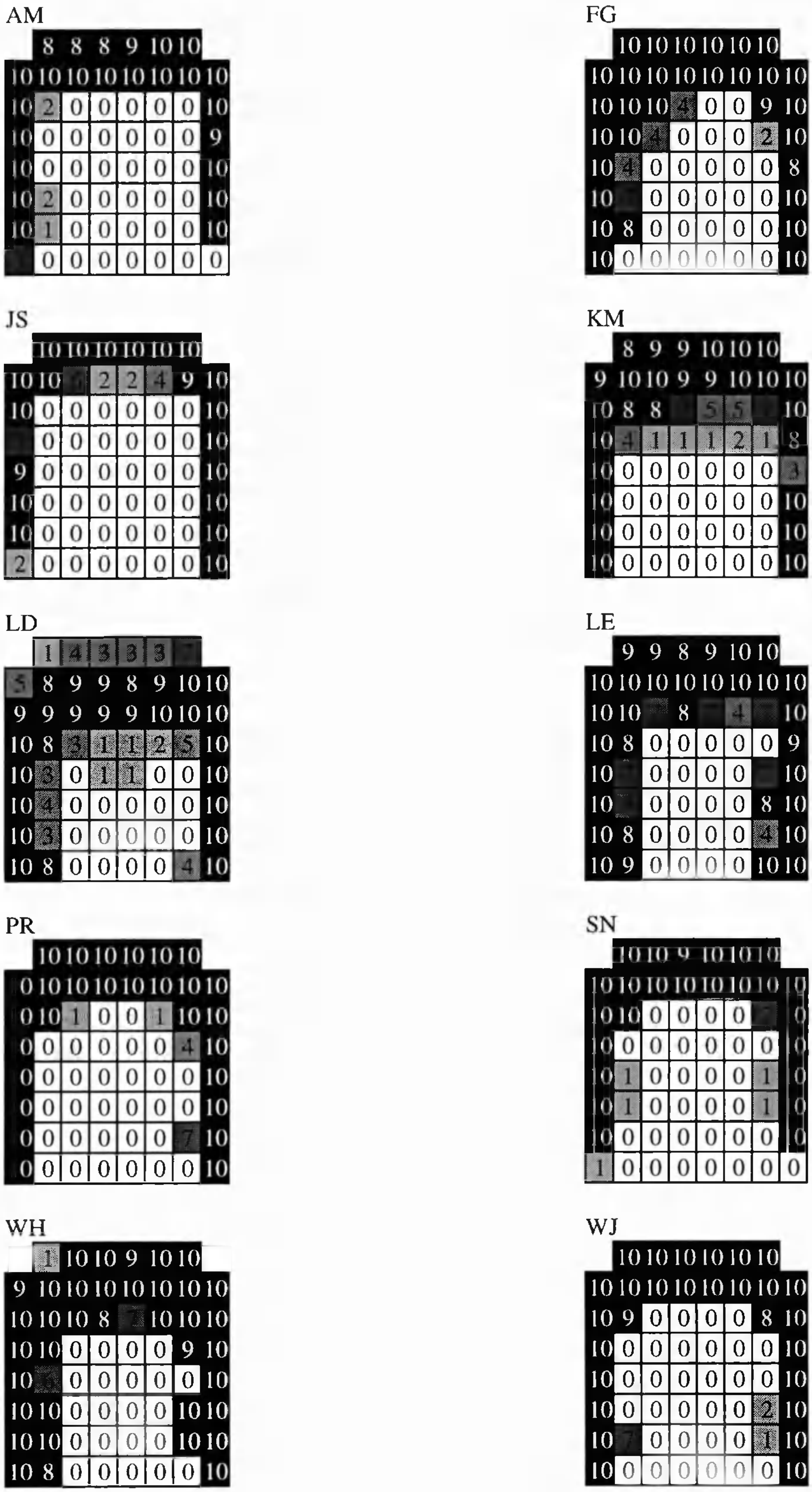


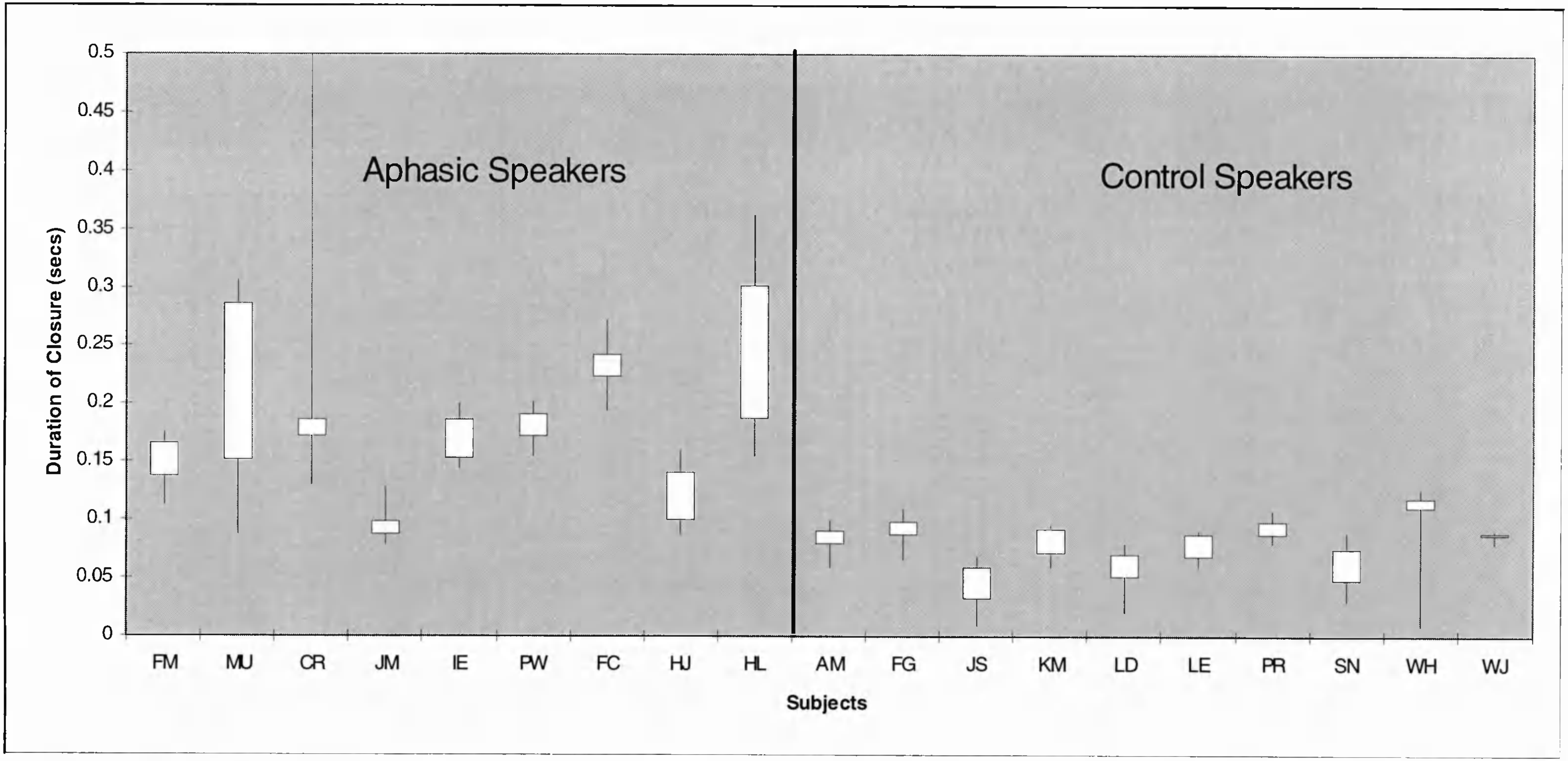
Figure 6-4: Prototypical frame of maximum closure for /d/ over 10 repetitions (control speakers).

6.1.5 Duration of /k/ closure in "kitkat"

A measure of the /k/ closure in "kitkat" was made from the EPG trace. The starting point was taken as the first frame of full closure in the velar region or, where full closure was not indicated on the EPG trace, annotation was made from the acoustic waveform. A point soon after the end of regular glottal pulsing for the indefinite article where the EPG contact patterns were relatively stable was chosen to indicate the start of velar stop articulation. The release was the last frame of full closure in the velar region or the burst of energy seen from the acoustic waveform if full closure was not made. A box and whisker graph (Graph 6-2) shows the interquartile ranges plus the maximum and minimum values for all aphasic and control speakers (for data see Appendix D). Scatterplots were drawn (Figure 6-5, aphasic and Figure 6-6, control) to visually display variability of durations over 10 repetitions.

Similar to the data from production of "deer", (Graph 6-1) Graph 6-2 shows that the aphasic speakers generally produce closure phases that are longer in duration than the control speakers' (all except JM). Three of the aphasics (MU, CR and HL) appear to have durational ranges which are much greater than the control speakers. These subjects are diagnosed as Broca's with AOS, Broca's without AOS and anomic respectively. Therefore the durational patterns do not seem to be related to a particular aphasia syndrome but rather a subject specific feature. Furthermore, only two of the subjects (MU and CR) produced a larger range in duration compared to the control speakers for the previous word, "deer". HL did not.

The scatterplots (Figure 6-5 and Figure 6-6) emphasize the variability in duration demonstrated by these 3 subjects and also the overall longer duration of the closure phase that all the aphasic subjects produce except JM. The control subjects' productions appear to be more variable for the production of /k/ in "kitkat" compared to the /d/ in "deer" (see Figure 6-2).



Graph 6-2: A box and whisker graph showing the interquartile ranges (box) and the minimum and maximum durations of /k/ closure over 10 repetitions of the word "kitkat" for 9 aphasic speakers (FM, MU, CR, JM, IE, PW, FC, HJ and HL) and 10 control subjects (AM, FG, JS, LD, LE, KM, PR, SN, WH, and WJ).

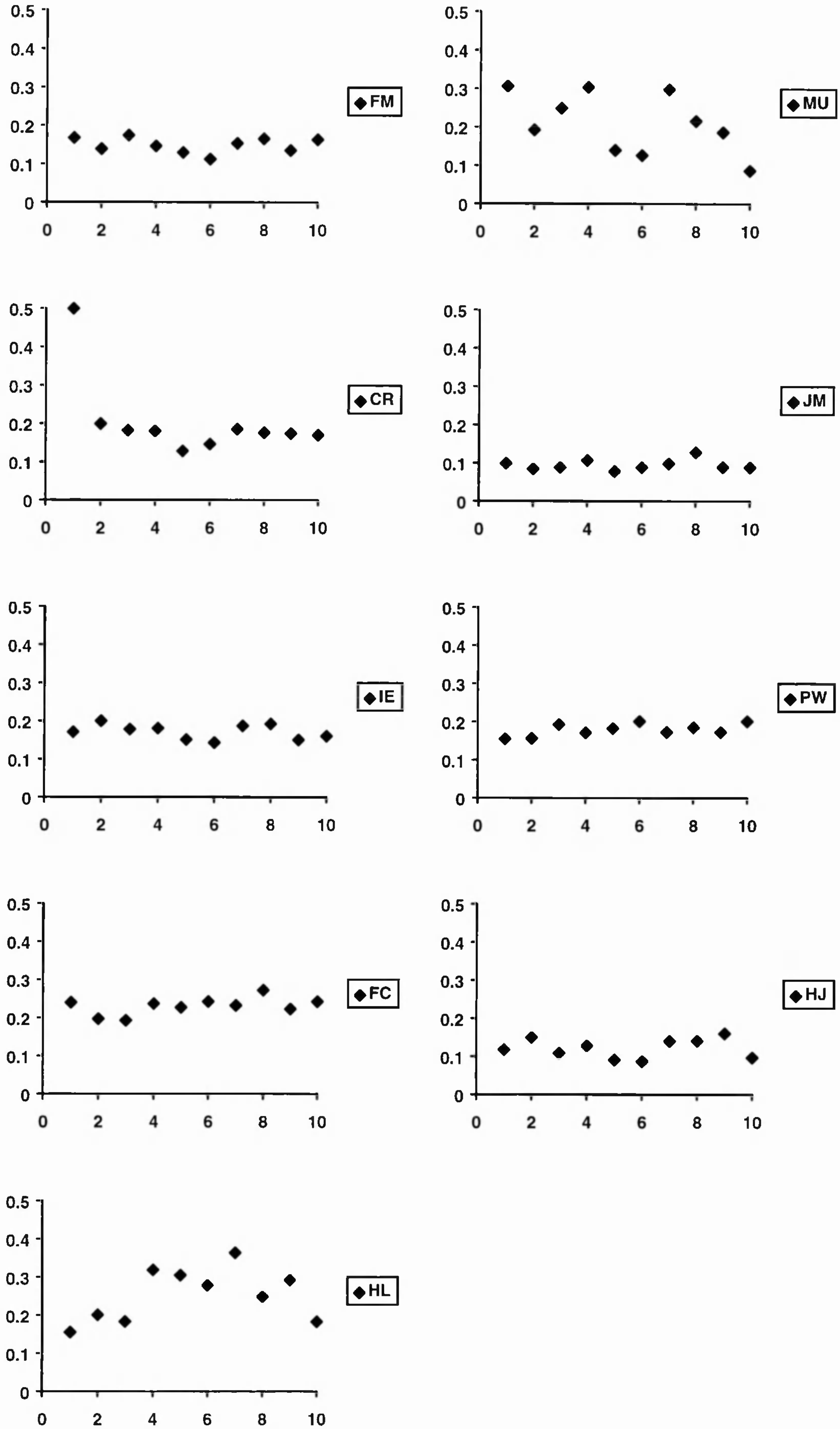


Figure 6-5: Scatterplots detailing variability of duration for /k/ closure in "kitkat" for aphasic subjects. X axis represents the number of repetitions, Y axis represents the time in seconds.

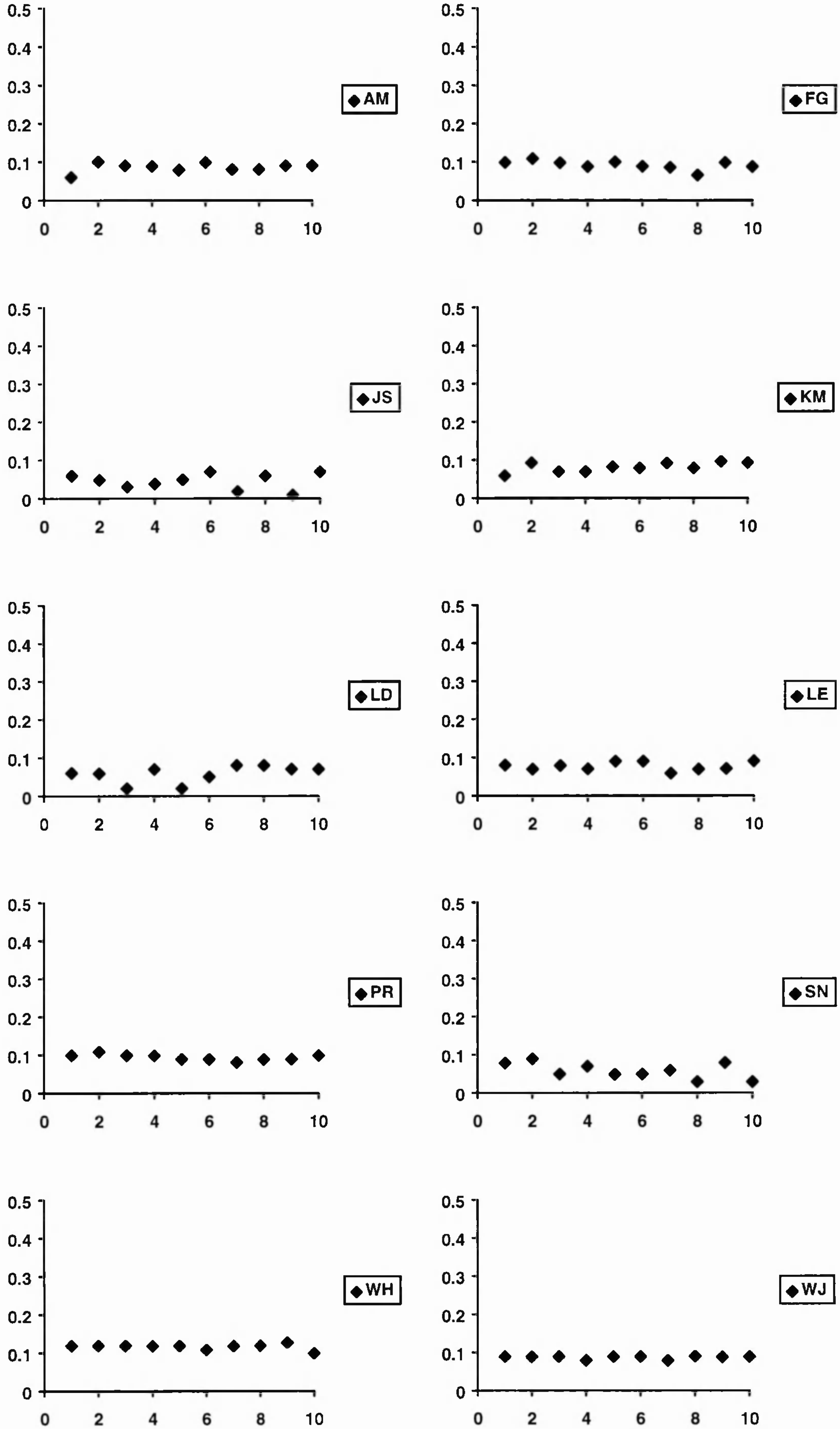


Figure 6-6: Scatterplots detailing variability of duration for /k/ closure in "kitkat" for control subjects. X axis represents the number of repetitions, Y axis represents the time in seconds.

A test of variance assessed whether the aphasic productions over 10 repetitions were more variable than the control speakers'. F scores for each subject are given in Table 6-5 (calculations can be found in Appendix D).

Subject	Speech Diagnosis	F value	Null Hypothesis $\sigma_1^2 = \sigma_2^2$
FM	Broca's with AOS	0.887	cannot reject
MU	Broca's with AOS	13.5	reject
CR	Broca's without AOS	25.26	reject
JM	Broca's without AOS	0.470	cannot reject
IE	conduction	0.880	cannot reject
PW	conduction	0.609	cannot reject
FC	anomic	1.195	cannot reject
HJ	anomic	1.517	cannot reject
HL	anomic	10.989	reject

Table 6-5: F values calculated by the test of variance for the duration of /k/ in "kitkat" for aphasic speakers. Critical value for $\propto$ = 0.05 is F = 1.97. Rejection of the Null hypothesis is indicated where appropriate.

The null hypothesis ($\sigma_1^2 = \sigma_2^2$) could be rejected (95% confidence level) for three aphasic subjects (MU, CR and HL) who were identified as showing increased ranges in duration.. Both MU and CR were more variable in their productions of the phoneme /d/ in "deer". However, HL, who demonstrates a significantly greater amount of variation than the control speakers for production of /k/ in "kitkat", showed very little variation of duration in his production of /d/ in "deer" (F value = 0.606 for "deer", 8.368 for "kitkat").

FC and HJ who demonstrated significantly more variability in duration of the stop closure in "deer" compared to the control speakers did not produce an increase in variability for word initial velar stop closure in "kitkat".

6.1.6 Spatial variability of the /k/ closure

The variability index (VI) (Farnetani and Provaglio, 1991) was used to assess the variability of lingual palatal contacts during production of the velar plosive /k/. The frame chosen for comparison was the first frame of velar closure (annotation the same as for duration of /k/ closure, see Section 6.1.5). This frame was chosen instead of the frame of maximum contact since many of the aphasic speakers made errors of articulation for this consonant involving the alveolar region. Therefore the frame of maximum contact may not have shown complete closure in the velar region although full closure may have been produced at some point during the articulation. Table 6-6 gives the calculated values from the VI for both aphasic and control speakers.

Aphasic	Variability Index (VI)	Control	Variability Index (VI)
FM	0.81	AM	2.10
MU	11.29	FG	2.58
CR	4.03	JS	1.45
JM	0.81	KM	1.45
IE	19.68	LD	2.10
PW	3.55	LE	3.23
FC	1.61	PR	1.61
HJ	7.26	SN	1.45
HL	3.87	WH	3.06
		WJ	4.35
mean	5.88	mean	2.34
standard deviation	6.17	standard deviation	0.97

Table 6-6: Absolute variability calculated by the VI (Farnetani and Provaglio, 1991) for aphasic and control subjects for word initial /k/ in "kitkat".

The aphasic speakers as a group show less consistency in their lingual/palatal contact over 10 repetitions compared to the control speakers during production of the velar plosive. Unlike their production of the alveolar plosive in "deer", two of the aphasic speakers record the lowest score on the VI (FM, JM: 0.81). Three of the aphasic speakers demonstrate variability which is greater than the control speakers (MU, IE and HJ). These speakers all differ in their aphasia diagnosis (Broca's with AOS, conduction, and anomic aphasic respectively). Therefore the increased variability appears to be related to the subject and not one particular aphasia syndrome.

A test of variance was carried out to compare the scores calculated by the VI from the two groups. The calculation and hypotheses are as follows:

Null hypothesis (H_0): $\sigma_1^2 = \sigma_2^2$

Alternative hypothesis: (H_1): $\sigma_1^2 \neq \sigma_2^2$

Critical F values for V1: 89; V2: 99 (nearest in statistical table 100:100):

F = 1.483 for $\alpha = 0.05$

$$F = \frac{S_1^2}{S_2^2} \quad \frac{(\text{standard deviation of group 1})^2}{(\text{standard deviation of group 2})^2}$$

$$F = \frac{6.17^2}{0.97^2} = 40.46$$

The null hypothesis can be rejected at the 5% confidence level. Therefore there is a statistically significant difference between the standard deviations of both groups of speakers. However, it would seem likely that this is directly related to the high variability indicated by HJ, IE, and MU since the scatterplots highlight that many of the values calculated by the VI for the other aphasic speakers are similar to the control speakers.

The EPG frames for the first frame of full closure or frame of maximum closure in row 8 for aphasic and control speakers are shown in Figure 6-7 (aphasic) and Figure 6-8 (control). What is clearly evident from Figure 6-8 is that the contacts for all control subjects are concentrated over the back portion of the palate. The majority of contacts are made from row 5 through to row 8. In contrast, four out of the nine aphasics show contacts that spread further forward on the palate (see Figure 6-7). MU, IE, HJ and HL (Broca's with AOS, conduction, anomic and anomic respectively) make contacts throughout rows 1 to 8 during some repetitions. For MU, HJ and HL these are infrequent with the higher concentration of contacts being to the rear of the palate similar to the control speakers. However, for IE there seems to be no one area which is consistently contacted.

A comparison was made to see whether those subjects who demonstrated increased durational variability also produced an increase in the variability of lingual/palatal contacts as indicated by the VI. The null hypothesis ($\sigma_1^2 = \sigma_2^2$) for duration of /k/ closure was rejected for MU, CR and HL indicating significantly more variability in their productions compared to the control group. Only two of the aphasics (MU, Broca's with AOS and HL, anomic) showed greater variability than the control subjects for both temporal and spatial measures. The values calculated by the VI for MU and HL (11.29, 3.87 respectively) were more than +1 standard deviation above the mean value calculated for the control speakers (mean = 2.34, σ = 0.97).

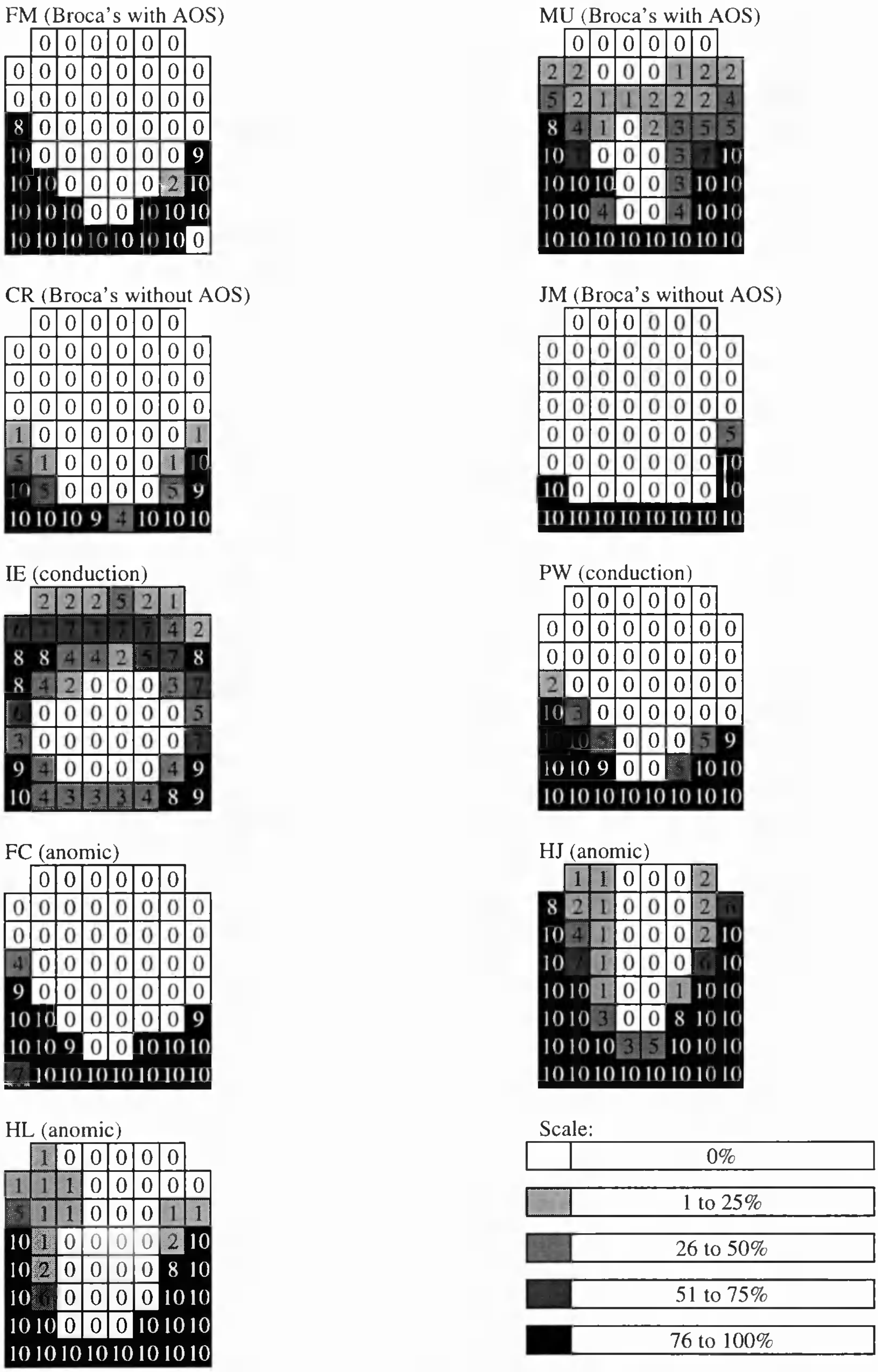


Figure 6-7: Prototypical frame indicating the start of velar closure for 10 repetitions (aphasic speakers).

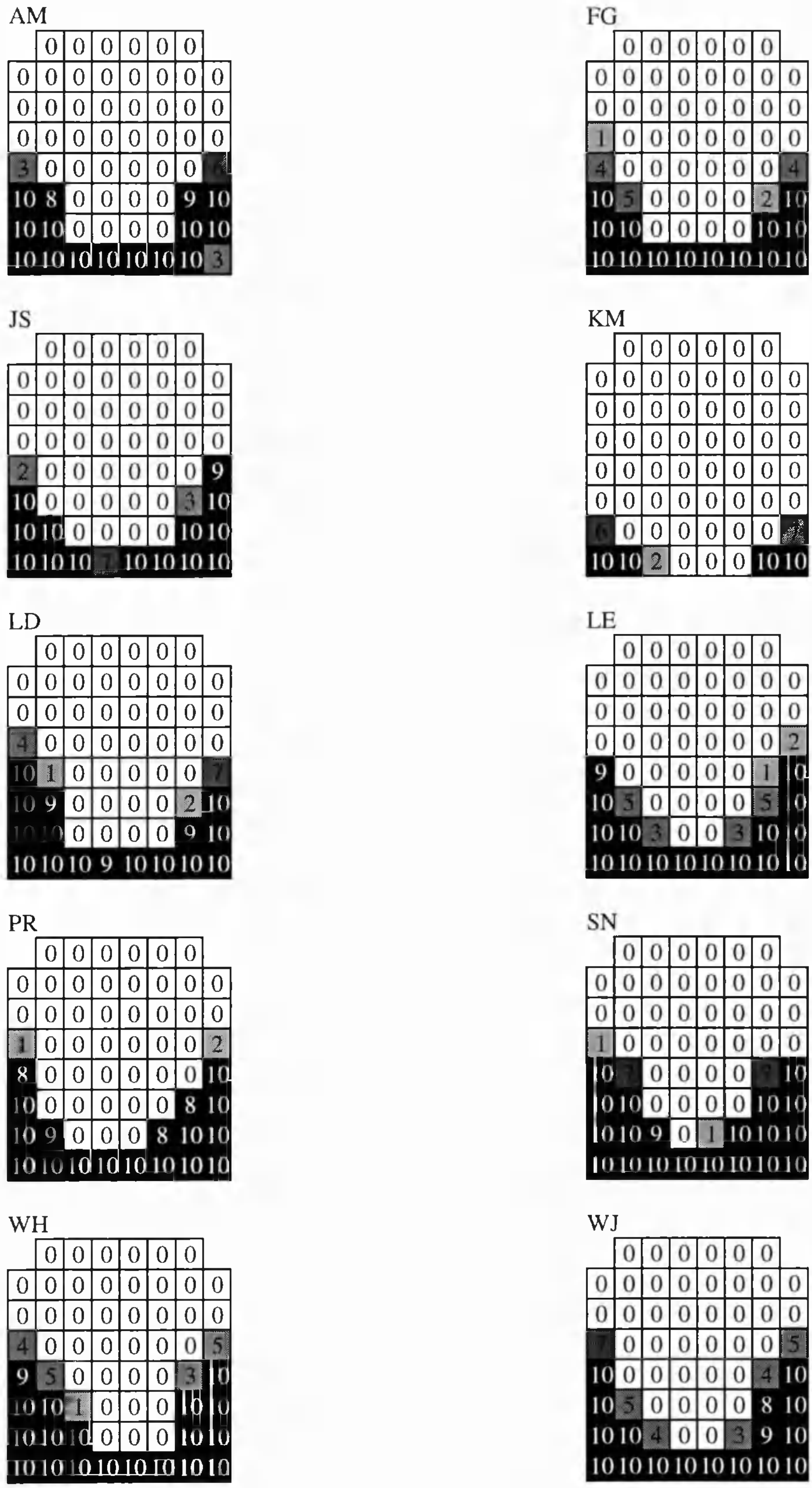


Figure 6-8: Prototypical frame indicating the start of velar closure for 10 repetitions (control speakers).

6.1.7 Summary of results

The following are the main points arising from analysis of the variability of successive repetitions:

6.1.7.1 Temporal variability of the word "deer"

1. The aphasic speakers generally produce longer stop closures.
2. Four of the aphasics produce closure phases which are statistically more variable compared to the control speakers (MU, Broca's with AOS; CR, Broca's without AOS; FC, anomic; HJ, anomic).
3. The duration of the whole word "deer" is longer for one aphasic speaker MU (Broca's with AOS) compared to the control speakers.
4. The proportion of the /d/ closure in relation to the whole word is statistically different for one aphasic (IE, conduction aphasic) compared to the control group.

6.1.7.2 Spatial variability of the word "deer"

1. The mean VI value calculated for the aphasic speakers is greater than the control group but this was not statistically significant.
2. The aphasic speakers tend to use more lateral contacts during the stop closure compared to the control speakers. These additional contacts are along the lateral margins of the palate.
3. An increase in contacts was subject specific and not associated with a particular aphasic syndrome.

6.1.7.3 Relationship between temporal and spatial variability during production of the word "deer"

1. One subject (HJ, anomic) whose productions were characterized by increased temporal variability also demonstrated greater spatial variability.

6.1.7.4 Temporal variability of the word "kitkat"

1. The aphasic speakers produce longer velar stop closures compared to the control group.
2. The control subjects productions of /k/ in "kitkat" compared to the /d/ in "deer" are more variable.
3. Three of the aphasics produce closure phases which are statistically more variable compared to the control speakers (MU, Broca's with AOS; CR, Broca's without AOS; HL, anomic).

6.1.7.5 Spatial variability of the word "kitkat"

1. The calculated mean VI value for the aphasics is greater as is the standard deviation indicating an increase of values.
2. The aphasic speakers show statistically more spatial variability.

6.1.7.6 Relationship between temporal and spatial variability during production of the word "kitkat"

1. Two of the three aphasic speakers (MU, Broca's aphasic with AOS; HL, anomic) who demonstrated greater temporal variability also show increased spatial variability.

6.2 Sequencing

6.2.1 Coarticulation

The production of a velar/alveolar stop sequence, for example the WI /kl/ sequence in "clock" or an alveolar/velar stop sequence, for example the /tk/ sequence in "kitkat", involves the temporal coordination of the tongue tip/blade system and the tongue body which can be viewed as two different control systems (Hardcastle, 1976). Analysis of the production of these sequences will identify any coarticulation of the tongue tip and the tongue body. Ten repetitions of the words "clock" and "kitkat" were produced by 9 aphasic speakers and all the control speakers. These will be analysed separately.

6.2.2 Duration and sequencing of the phonemes /k/ and /l/ in the word initial /kl/ sequence for "clock"

Several aspects of the production were analysed:

a) Duration of the /kl/ sequence.
b) Extent and type of the temporal overlap of the /k/ and /l/.
c) Spatial variability of successive productions.

In his study of phonetic and syntactic constraints on lingual coarticulation during /kl/ sequences, Hardcastle (1985) identified four patterns which were used to classify the sequencing of the two phonemes. These are summarized in Table 3-6, Chapter 3.

Hardcastle observed "considerable difference between subjects in their coarticulatory patterns" (p.255). Most speakers freely coarticulated the anterior part of the tongue with the back of the tongue during the production of /kl/ clusters. Whilst syntactic constraints had very little influence, Hardcastle found that the "most consistent and important influence on the degree of coarticulation is the rate of utterance" (p.260).

The patterns identified by Hardcastle (1985) provide a useful means of classifying the data gathered from repetition of the word "clock". Type 2 and type 3 patterns were collapsed into a single category (type 2) which included the approach to the /l/ during the /k/ closure period plus the /l/ approach and part of the alveolar closure overlapping with the /k/ closure. These categories were collapsed because only EPG and the corresponding acoustic trace were available to segment the data in the present investigation. Hardcastle was better able to segment the data because of the additional information from pneumotach recordings.

In this study four annotation points were made to capture any temporal coarticulation. These points are listed below.

SCEW (Stop Closure for the velar stop measured from the EPG or Waveform). This indicated the start of velar closure. It was taken as the first frame of full closure in the velar region identified from the EPG trace. In cases where full closure was not seen on the EPG trace, annotation was made from the acoustic waveform.

A point at the end of regular glottal pulsing for the indefinite article where the EPG contact patterns were relatively stable was chosen to indicate the start of the velar stop articulation.

SREW (Stop Release for the velar stop measured from the EPG or Waveform). This indicated the release of full velar closure. Normally this point was clearly indicated on the EPG pattern as a sudden decrease in activated electrodes coinciding with the burst of acoustic energy seen on the waveform. If this was not identifiable from the EPG print-out then the point of release was taken as the burst of energy seen on the acoustic waveform (see Figure 6-9).

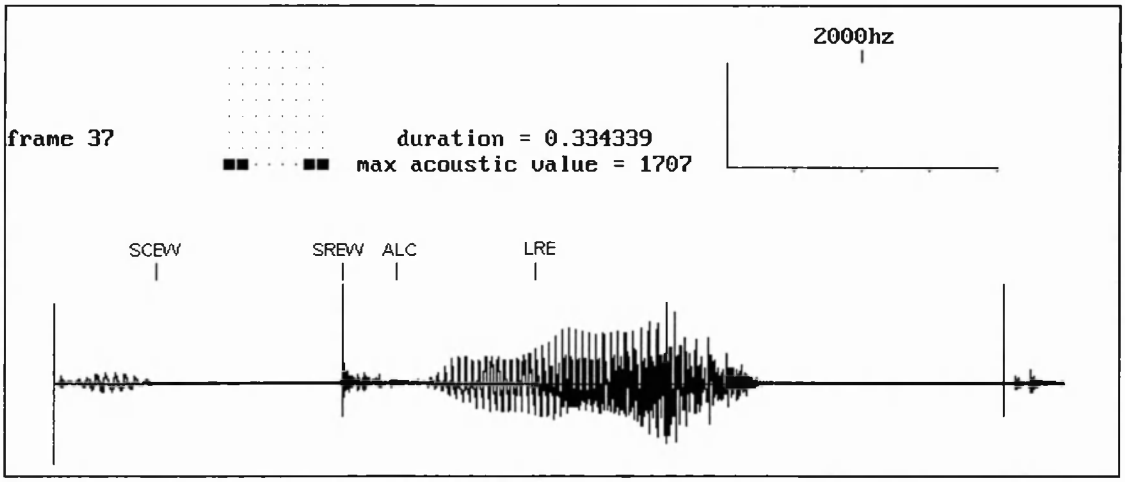


Figure 6-9: Burst of energy on acoustic waveform at point SREW indicating the release of the velar closure of the /kl/ sequence in word initial position for the word "clock" (taken from KM repetition 6).

ALCE (Approach to Lateral Closure Taken from the EPG trace) This was taken as the first frame showing any contact in rows 1 or 2. Where the resulting articulation was felt to be retracted, the first frame with any contact in row 3 was taken to be ALCE.

LRE (Lateral Release taken from the EPG trace) was taken as the first frame showing release of the full closure in the alveolar region of the palate.

Graphs detailing the sequencing of the phonemes were constructed for all repetitions (see Graph 6-3 to Graph 6-21 at the end of this chapter). A reference point "0" on the x axis was taken as the end of regular glottal pulsing of the preceding vowel (indefinite article). This was chosen instead of SCEW or LRE because some of the aphasics failed to produce either a velar stop pattern or lateral articulation. Therefore a reference point could not be based on the production of one of the phoneme targets. In addition a misdirected articulatory gesture was sometimes seen prior to the velar articulation but following the indefinite article. Since this may signify some difficulty in the sequencing and programming of the articulators for the /kl/ cluster it was included on the graphs.

6.2.3 General observations

Initial analysis of the aphasic speech revealed that the four pattern types identified by Hardcastle (1985) (Table 3-6, Chapter 3) were not sufficient to classify the aphasic productions of the /kl/ clusters. Therefore three new patterns were added to allow classification of the phoneme sequencing in the aphasic speech. These are listed in Table 3-7, Chapter 3.

Each production was classified according to the pattern types described and are summarized in Table 6-7 (aphasic) and Table 6-8 (control).

Aphasic	Diagnosis	Sequencing Pattern Type						
		1	2	4	5a	5b	6	7
FM	Broca's with AOS		6	2	2			
MU	Broca's with AOS					10*		7*
CR	Broca's without AOS				1	8	1	
JM	Broca's without AOS	1				9		
IE	conduction	10						
PW	conduction	10						
FC	anomic	1	8			1*		1*
HJ	anomic	10						
HL	anomic	10						
Incidence of each pattern type		42	14	2	31		1	
Percent total of each pattern type		46.7	15.6	2.2	34.4		1.1	

Table 6-7: Incidence of sequencing patterns during /kl/productions (aphasic speakers).

Control		Sequencing Pattern Type						
		1	2	4	5a	5b	6	7
AM		8	2					
FG		7	3					
JS		7	3					
KM		10						
LD		1	9					
LE		6	4					
PR			10					
SN		10						
WH		10						
WJ		2	8					
Percent total of each pattern type		61	39					

Table 6-8: Incidence of sequencing patterns during /kl/productions (control speakers).

Table 6-7 and Table 6-8 summarizes the incidence of each type of sequencing pattern for /kl/ clusters over 10 repetitions of the word "clock" for 9 aphasic and all control speakers. Those marked with an asterisk (*) indicate that the subject omitted the target phoneme but also produced a MAG.

What is immediately obvious is the use of type 1 and type 2 patterns for the control speakers compared with the aphasic speakers whose productions are not restricted to these pattern types. The percentage of each pattern type for the aphasic speakers and the control speakers can be found in the bottom rows of Table 6-7 and Table 6-8 respectively[3]. Both groups use type 1 patterns most frequently. However, the aphasic group more frequently omit a phoneme (pattern type 5) than produce a type 2 pattern (34.4% compared to 15.6%). It is the lateral /l/ which is more often omitted (28/31 = 90%) than the velar stop. The omission of a phoneme is not seen in the speech of the control subjects. Occurrence of type 7 patterns (MAGs) were restricted to when the aphasic speaker omitted the phoneme /l/. All MAGs were alveolar articulations but they appeared spatially different to lateral approximants typical for that subject. An example of an MAG compared to a typical /l/ production for FC is shown in Figure 6-10.

[3] Percentage calculations do not include type 7 patterns produced by aphasic subjects since all intrusive gestures were identified when an target phoneme was omitted and therefore these productions are also included under sequencing pattern type 5a or 5b.

```
  92
000000
00....00
0......0
.......0
0......0
0......0
0......0
0.....00
```
Repetition 9
Typical /l/ pattern

```
  60
000000
00000000
00....00
00....00
00.....0
00.....0
00....00
00....00
```
Repetition 1
Misdirected articulatory gesture

Figure 6-10: Comparison of a typical /l/ gesture produced by FC (repetition 9) and a misdirected articulatory alveolar gesture (repetition 1).

These MAGs most frequently occurred prior to the velar articulation and continued into part of the velar stop gesture (6/8). They were usually released before the release of the velar stop (5/6). Only one MAG commenced before the velar articulation and was not released until after the velar stop was released (Graph 6-9: FC repetition 1(R1)). Therefore the resulting velar stop had alveolar contacts throughout. For details of the temporal arrangements of these MAGs see Graph 6-4 (MU) and Graph 6-9 (FC).

Whilst the aphasics as a group demonstrate a greater number of pattern types this was not typical of all the subjects. Five out of nine aphasics produced 10 repetitions which were classified under one pattern type. IE, PW, HJ and HL produced only type 1 patterns, whilst MU produced all type 5b (with associated MAGs during 7 of the 10 repetitions). For these five subjects the sequencing of /k/ and /l/ phonemes was consistent.

6.2.4 Duration of the /kl/ sequence

The mean duration and standard deviation for the word initial stop closure over 10 successive repetitions for all aphasics and control subjects was calculated (see Table 6-9). Duration was taken as a measure in milliseconds between SCEW and LRE. Where the subject omitted a phoneme the duration of the single consonant (either /k/ or /l/) in word initial position was used. MAGs were not used in the calculations since these were not target gestures. Graph 6-3 to Graph 6-21 inclusive visually represent the duration and sequencing of these repetitions for all aphasic and control speakers.

Aphasic	Mean (msecs)	Standard deviation	Control	Mean (msecs)	Standard deviation
FM*	277	72.119	AM	185	21.731
MU*	248	79.554	FG	231	7.379
CR*	101	73.401	JS	202	14.757
JM*	103	21.108	KM	207	16.364
IE	234	15.776	LD	179	24.244
PW	279	30.350	LE	186	20.111
FC	308	29.364	PR	176	16.465
HJ	342	34.198	SN	149	9.944
HL	178	61.968	WH	190	14.907
BA	no data available		WJ	142	10.328

Table 6-9: Mean duration (msecs) and standard deviations for the word initial stop for 9 aphasic speakers and 10 control speakers. Those subjects marked with an asterisk (*) did not produce two gestures over the ten repetitions (see Graph 6-3 to Graph 6-21 inclusive for details on frequency and type of gesture omitted).

The mean durations of the /kl/ sequence for the control speakers ranged from 142 milliseconds to 231 milliseconds. Six out of the nine aphasics produce word initial stop sequences which were in excess of 231 milliseconds (FM, MU, IE, PW, FC and HJ) and of these six, two aphasics only produce one of the target gestures (FM and MU, both Broca's aphasics with AOS). These longer durations may be an artifact of a slower speaking rate which was not controlled for in this study. The standard deviations for the control speakers range from 7.379 to 24.244 msecs and for all aphasics 15.776 to 79.554 msecs. For those aphasics who produced the two target gestures the standard deviations range between 15.776 and 61.968 msecs. The range and size of the standard deviations is much greater for the aphasic subjects than the control speakers which suggests greater variability among the aphasics compared with the controls. However, the relationship is not quite that simple since it is commonly believed that the greater the value of the mean the greater the corresponding standard deviation. Since speech rate was not controlled for in this investigation and not all of the aphasics produced both /k/ and /l/ phonemes in the correct sequence it is not possible to run any statistical tests on the data. A different approach is needed to identify the differences which are specific to these aphasic patients. Graph 6-3 to Graph 6-21 inclusive are a clear visual representation of how consistent or inconsistent each subject was over ten repetitions of the word "clock". These show the duration of each phoneme and the relationship these have with one another (if more than one phoneme is produced).

Hardcastle (1985) found that for productions which were of type 1, the distance between SREW and ALCE "in the initial cluster environment is restricted typically to a maximum of 4 frames (= approximately 30ms)" (p.253). Analysis of the repetitions of "clock" in this investigation revealed that the maximum distance between the release of the velar stop closure and the approach to the lateral approximant was 80 milliseconds for control subjects and 90 milliseconds for the aphasic speakers. Therefore there seemed to be little difference in this delay period between the control and the aphasic speakers.

6.2.5 Intra-subject variability of sequencing /kl/ in "clock"

Intra-subject variability was assessed through analysis of the individual graphs showing the temporal and spatial relationship between the /k/ and /l/. The control speakers will be considered as a group (see Graph 6-12 to Graph 6-21 inclusive) since there was little variability between them, but the aphasic speakers will be discussed individually (see Graph 6-3 to Graph 6-11 inclusive).

6.2.5.1 Control speakers

The control subjects show very little intra-subject variability in their productions of the /kl/ sequence. For each individual the start frame for the /k/ closure (SCEW) and the release of the /l/ (LRE) are consistent in their distance from the end of regular glottal pulsing for the indefinite article. There is very little intra-subject variability in duration over the 10 repetitions for each control subject. The main inter-subject variability concerns the timing of SREW to ALCE. Whilst coarticulation of the two gestures is clearly evident for some (see Graph 6-16, Graph 6-18, Graph 6-21) indicated by a consistent overlap of the two shaded blocks (LD, PR, WJ) there is a clear gap between gestures for others (Graph 6-15: KM, Graph 6-19: SN, Graph 6-20: WH). The abutting of the two blocks indicates the approach to the /l/ simultaneous with the release of the velar articulation (see Graph 6-12: AM repetitions 1, 2, 6 and 10).

The aphasic speakers demonstrate both intra- and inter-subject variability. Each subject will be considered individually to highlight the inconsistencies.

6.2.5.2 FM (Broca's with AOS)

Graph 6-3 highlights the inconsistency of productions across ten repetitions. FM demonstrates a lack of uniformity in the production of consonants, their ordering and the duration of the word initial articulation. There is evidence of both /k/ and /l/ articulations for eight of the ten repetitions (not R2 and R4). The sequencing of the two phonemes is very consistent. Six of the productions (R1, R5, R7, R8, R9, and R10) are a type 2 pattern (approach to the /l/ during the /k/ closure period or /l/ approach and part of the alveolar closure overlapping with the /k/ closure). Point SCEW for these six repetitions varies in duration from the reference point "0". For example, R8's SCEW is 50 milliseconds after the end of regular glottal pulsing. In contrast, SCEW for R1 is 230 milliseconds post glottal pulsing. Whilst these six repetitions vary in onset, the overall durations of the /kl/ sequence (SCEW to LRE) for the six repetitions are fairly consistent (R1 = 310 msecs, R5 = 250 msecs, R7 = 270 msecs, R8 = 310 msecs, R9 = 260 msecs, R10 = 240 msecs).

FM produces two other repetitions (R3 and R6) where both phonemes are produced. However, the sequencing of these is very different to those already described. The lateral approximant /l/ not only commences prior to the velar but also finishes after the velar closure has been released. Therefore the velar stop is actually realized as a double alveolar/velar articulation. Whilst R3 and R6 show a similar relationship between the phonemes /k/ and /l/, the onset of articulation (ALCE) is different. For R3 ALCE occurs at the reference point "0", for R6 ALCE is 120 milliseconds later.

There are two further repetitions which are different again (R2 and R4). These are characterized by the omission of the velar stop. However the duration and position of ALCE are very different. For R2, the duration between ALCE and LRE is 110 milliseconds, for R4 the same segment is over twice the length at 240 milliseconds. R2 starting point is at the reference point. In contrast, the same point for R4 is 110 milliseconds after the end of regular glottal pulsing. Therefore whilst these two repetitions are characterized by a single phoneme, the duration and onset of these articulations are different.

It appears from Graph 6-3 that FM is inconsistent in both the type of sequence produced and the temporal arrangement of phonemes.

6.2.5.3 MU (Broca's with AOS)

The variability of this subject's productions is clearly seen from Graph 6-4. However, there is some consistency to be noted, specifically the absence of a lateral approximant in all productions. For seven repetitions a misdirected alveolar articulation was noted which was typical of a stop closure for this subject. These MAGs vary considerably in their length (compare R5 at 60 msecs with R2 at 510 msecs). They also differ with regards to the sequencing of the velar closure. Four of the MAGs are articulated and released prior to the velar closure (R1, R3, R4, and R5), one is released at the point of velar closure, SCEW (R2), and one commences prior to velar closure and overlaps briefly with it (R6). R9 shows a different pattern. The MAG occurs post SCEW and finishes only one frame (10 msecs) after SREW. R7 and R8 show a single velar articulation. Durations of the velar articulation over the ten repetitions vary considerably (170 to 360 msecs) with a standard deviation of 79.554 which is much greater than the control speakers.

In summary, MU consistently omits the lateral approximant and produces a misdirected alveolar articulation for seven repetitions. The duration and sequencing of these alveolar gestures is variable.

6.2.5.4 CR (Broca's without AOS)

Graph 6-5 clearly identifies the intra-subject variability of both the duration of individual phonemes and the sequencing and production of these. CR produced a single phoneme instead of a cluster for nine of the ten repetitions. Eight of these were single velar articulations and one was a single lateral articulation. In R4 CR produced both velar and alveolar lingual/palatal contacts but these were in the reverse order to the target sequence. The /l/ was articulated and released prior to the velar closure. The durations of the individual repetitions are also variable. SCEW varies from repetition to repetition. For example, in R9, closure for the velar articulation is 8 frames (80 msecs) after the end of regular glottal pulsing for the indefinite article. In R2 the same point occurs 49 frames (490 msecs) after regular glottal pulsing. The productions appear to become more consistent with time. R6 to R10 appear more uniform with similar points for start and finish.

The overall impression from Graph 6-5 is that CR produces much greater intra-subject variability than any of the control subjects especially with regard to the production and sequencing of individual gestures.

6.2.5.5 JM (Broca's without AOS)

With the exception of R7, this subject's productions appear consistent in both the distance SCEW is from the end of glottal pulsing and the duration of the closure (see Graph 6-6). For nine repetitions JM produces a single consonant, a velar stop articulation which was spatially normal. Only R7 includes the target lateral approximant. The uniformity of productions is clear from the graphical displays.

6.2.5.6 IE (conduction)

The regularity in temporal arrangement of /k/ and /l/ can be seen from Graph 6-7. All productions are of type 1, the release of the /k/ prior to the onset of the tongue tip/blade movement for /l/. The mean duration for the /kl/ sequence over 10 repetitions is 234 milliseconds which is greater than the calculated value for the control speakers. However, the standard deviation, 15.776 is within the range calculated for the controls (7.379 to 24.244). These figures and the graphical display reflect the consistency of productions over ten repetitions with regards to duration and sequencing of the /k/ and /l/.

6.2.5.7 PW (conduction)

Graph 6-8 detailing PW's ten repetitions of "clock" highlights that all productions are of type 1 pattern (release of the /k/ prior to onset of tongue tip / blade movement for /l/). A certain amount of variability can be seen for SCEW in relation to the reference point, the interval gap between SREW and ALCE and duration of the whole /kl/ sequence.

An ordered regularity of productions is the overall impression gathered from the graphical display.

6.2.5.8 FC (anomic)

The initial impression from Graph 6-9 is one of little variation from repetition to repetition. R3 through R10 are very similar in appearance. SCEW is between 10 and 40 milliseconds after regular glottal pulsing for the preceding indefinite article has ceased. ALCE occurs anywhere between the last 50 to 100 milliseconds of the velar stop articulation (type 2 pattern). The duration of the /kl/ sequence for R2 to R10 is also fairly consistent, ranging from 290 to 350 milliseconds. R1 and R2 are different from the other repetitions. For R2 FC produces a /k/ and an /l/ in the correct order but there is no period of overlap for these two phonemes (type 1 pattern). However, the overall duration of SCEW to LRE is similar in R2 to R10 (290 msecs). The first repetition of "clock" (R1) is different from the following repetitions for several reasons. In R1 FC omits the second phoneme /l/. However, there is evidence of an alveolar articulation but the spatial configuration of this as seen from the EPG trace is more typical of an alveolar plosive (/t/ or /d/) than a lateral for this subject (see Figure 6-11). This MAG occurs prior to the velar stop closure, 10 milliseconds after regular glottal pulsing for the indefinite article has ceased. The velar articulation occurs much later, 220 milliseconds after glottal pulsing. Furthermore, there is evidence of alveolar contact throughout. The resulting articulation is a double alveolar/velar articulation.

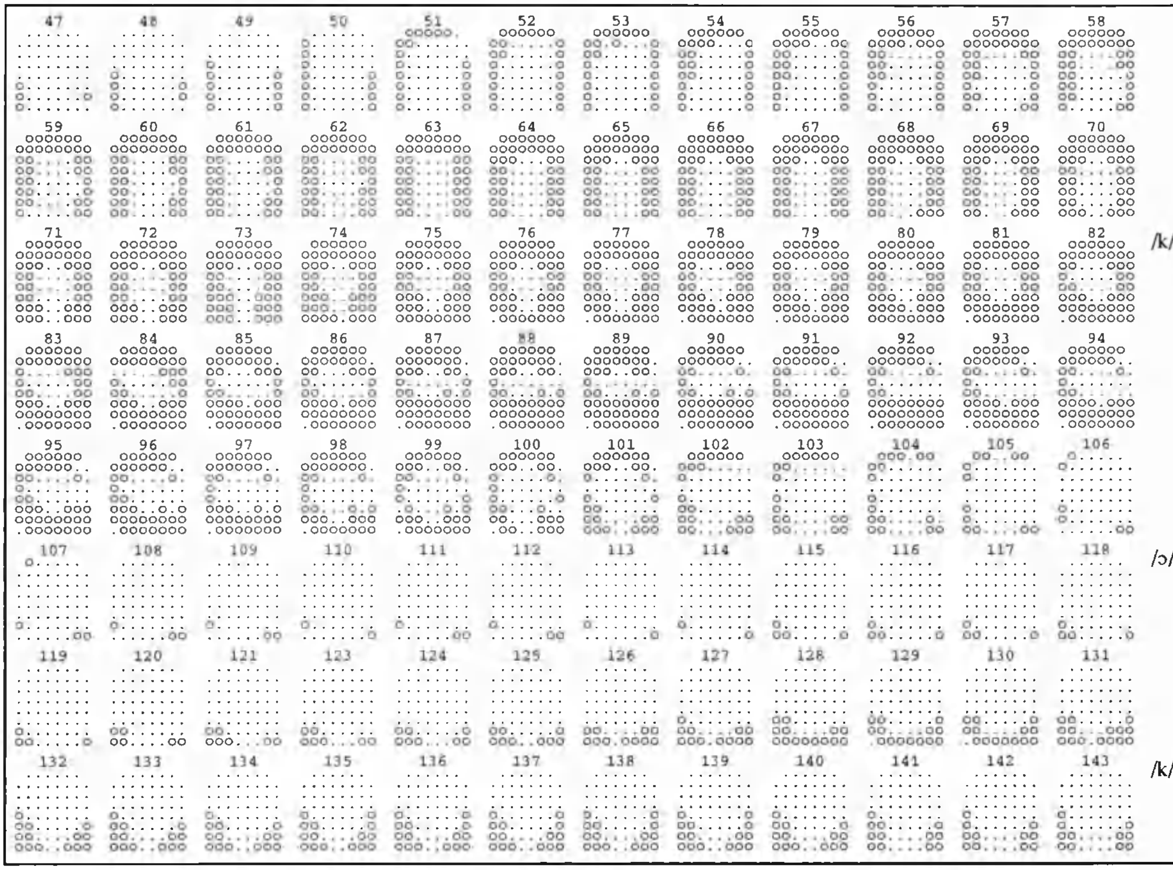


Figure 6-11: Lingual/palatal contact patterns for FC's first repetition of "clock" showing misdirected alveolar gesture commencing before the velar at frame 51.

The alveolar contact in Figure 6-11 is more typical of an alveolar plosive than a lateral approximant. Interestingly, the later repetitions became more consistent which is similar to CR. That is, R3 to R10 are uniform in their appearance but R1 and R2 are both different from each other and from later repetitions. However, the overall impression from Graph 6-9, with the exception of R1, is one of relatively consistent productions regarding duration and sequencing of the phonemes.

In summary, FC's productions from repetition 3 to repetition 10 are consistent both spatially and temporally. However, the first two productions differ to the latter articulations and to each other.

6.2.5.9 HJ (anomic)

This aphasic speaker showed consistency in some aspects of production but variability in others (see Graph 6-10). The temporal ordering of the /k/ and /l/ is consistently of type I pattern. However, the intervening period varies from one repetition to another. For example, points SCEW and ALCE share the same frame for R4 which indicates that the /k/ was released at the same time as the approach to the lateral approximant began. In contrast, there is a 80 millisecond delay between these two points in R2 and R3. The overall durations for the /kl/ sequence are not dissimilar. For HJ they range between 280 and 390 milliseconds with a standard deviation of 34.198. Standard deviations for the control speakers range between 7.379 and 24.244.

HJ demonstrates more variability than the controls but this maybe an artifact of the increased duration of contact especially for the /l/.

6.2.5.10 HL (anomic)

Graph 6-11 highlights the similarity between repetitions with the exception of R1. This first production is noticeably longer than the following 9 repetitions. All the other repetitions range between 140 and 180 milliseconds. The relationship between /k/ and /l/ is consistently of type 1. The large standard deviation for this subject (61.968) is a reflection of the increased duration for R1. However, from visual analysis of the Graph 6-11 the consistency of HL's productions is obvious. His productions are often shorter than the control speakers.

6.2.6 Spatial details of successive repetitions as seen from the EPG trace

The variability of the lingual/palatal contacts for the velar articulation only was assessed using the VI (Farnetani and Provaglio, 1991; see Section 3.4.3). Since three of the aphasic speakers (CR, JM, and MU) omitted the lateral approximant 80% or more of the time, spatial variability for the /l/ was not assessed using the VI. SCEW (the onset of velar closure) was chosen as the frame for comparison.

VI scores for SCEW are given in Table 6-10 below.

Aphasic	Speech Diagnosis	Variability Index (VI)	Control	Variability Index (VI)
FM	Broca's with AOS	6.61	AM	1.29
MU	Broca's with AOS	12.42	FG	0.00
CR	Broca's without AOS	4.31	JS	0.48
JM	Broca's without AOS	0.81	KM	0.65
IE	conduction aphasic	3.39	LD	5.32
PW	conduction aphasic	3.06	LE	0.97
FC	anomic	6.45	PR	4.68
HJ	anomic	10.97	SN	1.94
HL	anomic	1.29	WH	2.26
BA	no data available	-	WJ	3.55
mean		5.48	mean	2.11
standard deviation		4.05	standard deviation	1.83

Table 6-10: Absolute variability calculated by the VI (Farnetani and Provaglio, 1991) at the frame of onset for velar closure for aphasic and control subjects.

From Table 6-10 it is obvious that several of the aphasic speakers have scores which appear greater than the control speakers. Five of the nine aphasic subjects (MU, FM, CR, FC, HJ) have absolute variability scores which fall outside +1 standard deviations around the mean score for the control group (mean $= 2.11$, +1 standard deviation $= 3.94$). A test of variance was conducted to assess whether the aphasic group were statistically more variable than the control group. The Null Hypothesis (H_0) states that the standard deviation of group 1 (aphasic speakers) is equal to the standard deviation of group 2 (control speakers). The Alternative Hypothesis (H_1) states that the standard deviations of group 1 and group 2 are not equal. The nearest variance ratio statistic for $F_{86,99}$ given in standard F distribution tables is $F_{100,100} = 1.483$ for $\alpha = 0.05$. The calculation is as follows:

Null Hypothesis (H_0): $\sigma_1^2 = \sigma_2^2$

Alternative Hypothesis (H_1): $\sigma_1^2 \neq \sigma_2^2$

F= 1.483 for $\alpha = 0.05$

$F = \frac{S_1^2}{S_2^2}$ $\qquad$ $F = \frac{4.05^2}{1.83^2}$

F= 4.898

The null hypothesis ($\sigma_1^2 = \sigma_2^2$) can be rejected (95% confidence level). Therefore the aphasic group are more variable in their productions than the control speakers.

The scores calculated by the VI suggest that the spatial variability at the onset to the /k/ closure is subject specific for aphasics and not related to the aphasic syndrome. For example, FC, HJ and HL, all diagnosed as anomic have very different absolute variability values (6.45, 10.97, and 1.29 respectively). Whilst HL has a value which falls within +1 standard deviations of the mean, FC and HJ obtain values much greater than +1 standard deviation. Similarly, FM and MU, both diagnosed as Broca's aphasics with AOS have values of 6.61 and 12.42 respectively. Whilst these values are very different they are both above +1 standard deviation of the control group mean. CR and JM, Broca's aphasics without AOS, also have dissimilar scores (4.31 and 0.81 respectively). Furthermore CR's score is greater than +1 standard deviation for the controls, and JM's score falls just below the mean score. The only aphasic syndrome that appears to show some agreement in the amount of variability is conduction aphasia. The two conduction aphasics in this investigation (IE and PW) both have variability scores which are similar (3.39 and 3.06 respectively) and fall within 1 standard deviation of the mean score for the control speakers.

Lingual/palatal contacts made over the successive repetitions are summarized in Figure 6-12 (aphasic speakers) and

Figure 6-13 (control speakers). The chosen frame is the start of velar closure (SCEW). Where a subject did not produce ten velar articulations this is indicated above the palate diagram.

The overall impression from Figure 6-12 and

Figure 6-13 is that the aphasic speakers tend to make contacts over a wider range of the palate than the control group. The aphasic speakers are noticeably less consistent in their articulations. The control speakers concentrate their contacts in the velar portion of the palate, with some palatal contacts along the lateral margins. In contrast, several of the aphasics produce contacts in the alveolar and palatal regions as well as the velar (FM, MU, CR, FC and HJ).

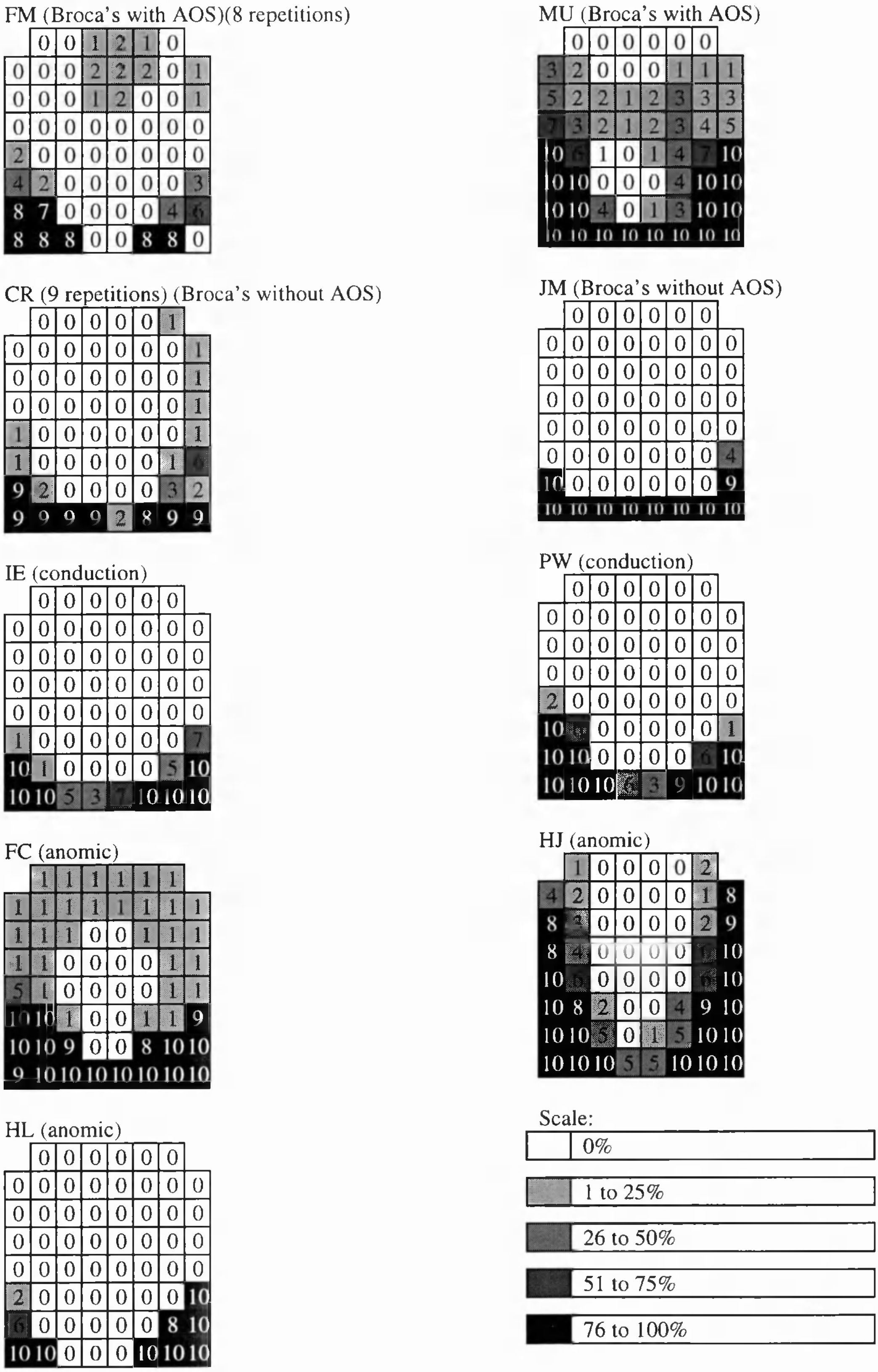


Figure 6-12: Prototypical frame indicating the start of velar closure over 10 repetitions (SCEW) for aphasic speakers.

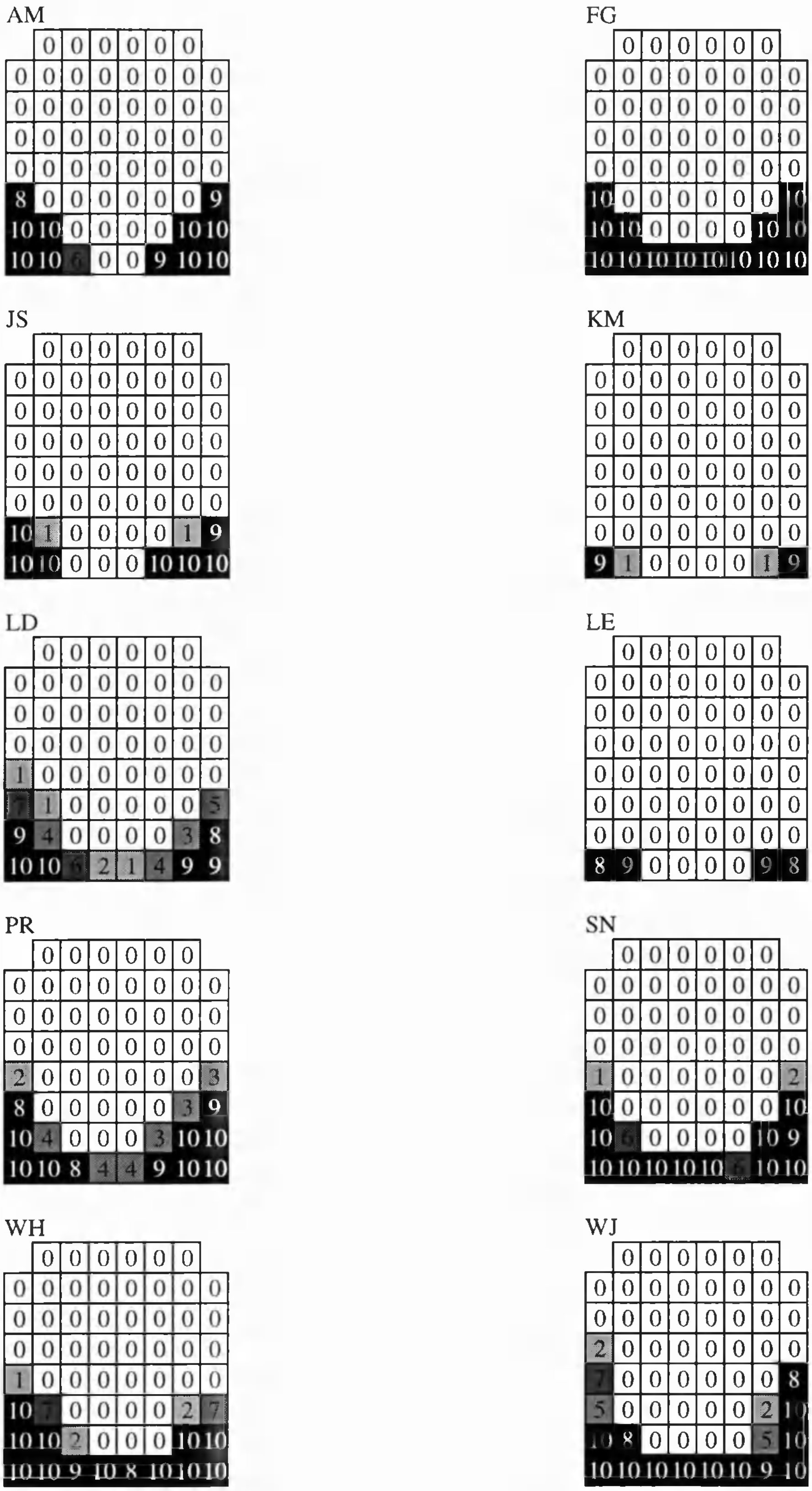


Figure 6-13: Prototypical frame indicating the start of velar closure over 10 repetitions (SCEW) for control speakers.

6.2.7 Duration and sequencing of the phonemes /t/ and /k/ in the word medial /tk/ sequence for "kitkat"

Temporal and spatial variability of the /tk/ sequence was measured by assessing the following:

a) Extent and type of temporal overlap.
b) Spatial variability of successive repetitions.

Four annotation points marked the onset and offset of both the /t/ and /k/ where present. These are detailed below:

ASC (Alveolar Stop Closure as identified from the EPG data). This was taken as the first frame showing full alveolar closure. If the speaker did not make full closure then the first frame of maximum constriction was taken as ASC. Constriction was not allowed to be greater than 2 electrodes wide to classify as an alveolar articulation.

ASR (Alveolar Stop Release). This was the first frame showing release of the alveolar stop closure or constriction.

SCEA (Stop Closure for the velar articulation identified from the EPG or Acoustic trace). indicated the start of velar closure. It was taken as the first frame of full closure in the velar region identified from the EPG trace. In cases where full closure was not seen on the EPG trace, annotation was made from the acoustic waveform.

SREA (Stop Release for the velar articulation measured from the EPG or Acoustic trace). indicated the release of the velar closure. If this was not visible from the EPG print-out then the point of release was taken as the burst of energy seen on the acoustic waveform.

Full closure was taken as the point of annotation for the second phoneme in the sequence rather than the approach to closure because often the approach was not visible from analysis of the EPG data and no clues regarding the approach phase are available from the acoustic trace. Therefore coarticulation for this sequence is defined differently to the coarticulation of the /kl/ sequence. For the /tk/ sequence coarticulation was defined as the presence of both full alveolar and full velar contact which resulted in a double alveolar/velar contact pattern similar to that seen in Figure 6-14 below.

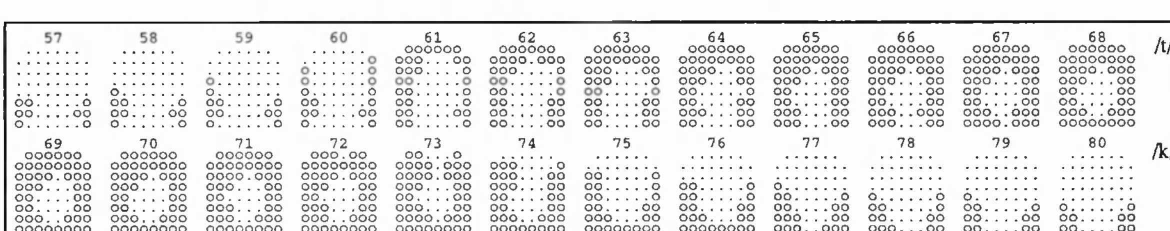


Figure 6-14: EPG pattern showing a double alveolar/velar articulation taken from FG repetition 5 of "kitkat". This type of coarticulation occurred when the alveolar closure for /t/ was not released until after full velar closure in the /tk/ sequence.

Following analysis of the data, several pattern types classifying the /tk/ sequence were identified from the control and aphasic speakers. These are described in Table 3-8, Chapter 3.

Graphs detailing the sequencing of the phonemes /t/ and /k/ were constructed for all repetitions (see Graph 6-22 to Graph 6-40 inclusive at the end of this chapter). A reference point "0" on the x axis marked the start of regular glottal pulsing for the vowel [ɪ] in syllable initial position. This was chosen instead of one of the annotation points described above since all subjects produced this vowel. However due to processes such as assimilation, omission or misarticulation not all repetitions contained all four annotation points. Therefore a reference point could not be based on one of these. Analysis of the graphs allowed the identification of the pattern type for each repetition for every subject. These are summarized in Table 6-11 (aphasic speakers) and Table 6-12 (control speakers) below.

Aphasic	Diagnosis	Sequencing Pattern Type						
		1	2	3	4	5	6	7
FM	Broca's with AOS	1	4	3		2		
MU	Broca's with AOS	1	3	1		1	1	3
CR	Broca's without AOS	1	4	4		1		
JM	Broca's without AOS							10
IE	conduction	10						
PW	conduction	9	1					
FC	anomic	7	3					
HJ	anomic	10						
HL	anomic	10						
Incidence of each pattern type		49	15	8	0	4	1	13
Percent total of each pattern type		54.4	16.7	8.9	0	4.4	1.1	14.4

Table 6-11: Sequencing patterns produced during production of /tk/ over 10 repetitions (aphasic speakers).

Control		Sequencing Pattern Type						
		1	2	3	4	5	6	7
AM		3	3	4				
FG		1	9					
JS		1	1	8				
KM				10				
LD				10				
LE		3	5	1	1			
PR			10					
SN				10				
WH		3	4	2	1			
WJ		5	2	2	1			
Percent total of each pattern type		16	34	47	3	0	0	0

Table 6-12: Sequencing patterns produced during production of /tk/ over 10 repetitions (control speakers).

Table 6-11 and Table 6-12 summarize the incidence of each type of sequencing pattern for /tk/ clusters over 10 repetitions of the word "kitkat" for 9 aphasic and all control speakers.

The number of pattern types used by each group varies as does the most frequent type. The control subjects use only types 1, 2, 3 and 4. In contrast the aphasic speakers use all patterns except type 4. Type 3, (assimilation of the /t/ to the velar position) is the most frequent pattern used by the control speakers, recorded 47% of the time. The aphasic group only used this pattern for 8.9% of their productions. Furthermore, this was used by eight of the ten control speakers (AM, JS, KM, LD, LE, SN, WH, and WJ) but only three aphasic speakers (FM and MU, Broca's with AOS, CR, Broca's without AOS). The most frequently recorded pattern for the aphasic group was type 1, defined as the release of the alveolar stop (ASR) prior to velar closure (SCEA). This was recorded 54.4% of the time compared to only 16% of control subject productions. Three of the aphasic speakers (HJ and HL, both anomic, and IE, conduction aphasic) produced only type 1 patterns and nine out of ten repetitions for PW (conduction) were also of type 1. The omission of the /k/ (type 7) was only observed in the speech of two aphasic speakers (JM, Broca's without AOS, MU, Broca's with AOS). All ten repetitions produced by JM were classified as type 7 compared to three for MU.

Reversal of the /tk/ sequence was rare (type 6). Only one aphasic, MU (Broca's with AOS), produced this pattern on a single occasion. Type 5 was also infrequent (4.4%), seen in the speech of three aphasics (FM and MU, both Broca's with AOS, CR, Broca's without AOS).

Classifying the production of /tk/ sequences into these pattern types highlights the different patterns used by each group and also the predominance of pattern types for the two groups. There appears to be some similarities amongst aphasics diagnosed with the same syndrome. For example, both HJ and HL (anomic) use type 1 patterns exclusively. FC, also anomic, uses this pattern for seven out of ten repetitions. The conduction aphasics (IE and PW) also favour this sequencing pattern. IE produces all type 1 sequences and nine out of a possible ten repetitions produced by PW are of this type.

6.2.7.1 Duration of the /tk/ sequence

The duration of the consonant sequence was not calculated due to inter-subject and intra-subject differences. Some aphasic and control speakers assimilated the two phonemes, others produced two separate phonemes and some aphasics omitted the /k/. This coupled with intra-subject variability on the type of pattern produced meant comparison of the duration in word medial position was not possible.

Graphs were produced to show intra-subject variability in sequencing patterns and durations (Graph 6-22 to 6-40 inclusive). These graphs show the duration of each phoneme and the relationship between them (if both are produced). The control speakers will be considered as a group but the aphasic speakers will be discussed individually.

6.2.8 Intra-subject variability of sequencing /tk/ in "kitkat"

6.2.8.1 Control speakers

The production of the /tk/ sequences by the control subjects (see Graph 6-31 to Graph 6-40 inclusive), whilst often variable in the type of pattern produced over ten repetitions, are relatively consistent in duration. Between one (KM, LD, SN) and four (LE, WH, WJ) different pattern types were seen for any one speaker. This variability was not seen during the /kl/ sequence in "clock" where only one or two pattern types were produced by each individual speaker. However, durational measures are relatively consistent. ASC is approximately the same distance for each repetition from the reference frame "0". Where type 1 patterns are recorded the distance between ASR and SCEA does not exceed 20 milliseconds. Therefore whilst the speakers may not coarticulate the two gestures there are no large intersyllabic pauses evident.

6.2.8.2 FM (Broca's with AOS)

The point of alveolar stop closure for all repetitions is between 100 and 190 milliseconds from the reference point and the distance between ASC and SREA appears consistent. The type of sequencing pattern varied between repetitions. Assimilation of the /t/ to the velar place of articulation was seen during three repetitions, four repetitions were characterized by full velar closure prior to the release of the alveolar stop resulting in a period of double articulation, two productions showed full velar closure prior to the alveolar stop and released following the release of the alveolar, and one repetition evidence full release of the alveolar stop before full closure for the /k/. Despite these differing patterns the duration of the word medial sequence remained relatively stable which can be seen from Graph 6-22.

FM's productions are characterized by differing patterns of sequencing and duration of individual phonemes but the overall timing of the word medial sequence was relatively consistent.

6.2.8.3 MU (Broca's with AOS)

Graph 6-23 indicates that MU is inconsistent in the sequencing pattern type used over the ten repetitions. Alveolar contacts appear to be of consistently increased duration compared to the control speakers but velars are temporally more variable. However, the overall durations of the /tk/ sequence and the distance from the reference point are relatively consistent. Therefore the time slot for the sequence appears consistent which is similar to FM.

6.2.8.4 CR (Broca's without AOS)

Similar to productions of /kl/, CR becomes more consistent over repetitions with respect to duration of the segment (see Graph 6-24). Duration of ASC to SREA for R1 is 480 milliseconds, for R3 the same interval is 190 milliseconds. Following this the productions become more alike with overall stop durations ranging from 170 to 200 milliseconds (although some WM stop sequences involve one phoneme and the others two phonemes). Of interest is the long duration from ASR to SCEA in R1 which far exceeds the same portion recorded for the control speakers where the maximum time delay was 20 milliseconds.

6.2.8.5 JM (Broca's without AOS)

The graphical display of JM's repetitions (Graph 6-25) appears consistently abnormal since the productions are restricted to type 7 patterns. The duration of alveolar closure over successive repetitions appears variable. R7 is only 30 milliseconds long but R6 is four times as long at 120 milliseconds. Therefore whilst JM is consistent in the sequencing pattern temporal measures are variable.

6.2.8.6 IE (conduction)

The ten repetitions produced by IE appear consistent in duration and the temporal relationship between the /t/ and /k/ (Graph 6-26). However distance ASR to SCEA for all repetitions is much greater than the control speakers, ranging from 110 milliseconds to 200 milliseconds.

6.2.8.7 PW (conduction)

The duration of the /tk/ sequences for PW appear inconsistent and much longer compared to the control speakers (see Graph 6-27). For type 1 patterns, the distances between ASR and SCEA are greater than those of the control speakers, ranging from 0 milliseconds (R5) to 80 milliseconds (R4) (control speakers do not exceed 20 msecs).

6.2.8.8 FC (anomic)

Graph 6-28 for FC shows repetitions which are relatively consistent both in duration and the distance ASC is from the reference point. The distances between ASR and SCEA for type 1 patterns range from 0 milliseconds to 60 milliseconds. Five of the repetitions (R3, R4, R5, R6 and R8) are in excess of 20 milliseconds.

6.2.8.9 HJ (anomic)

HJ is consistent in the type of sequencing pattern produced (all type 1) (see Graph 6-29). Durations between ASR and SCEA appear much longer than those observed for the control speakers with distances ranging from 110 milliseconds (R1) to 260 milliseconds (R4) and the duration of the alveolar closure also varies between 40 and 110 msecs which is greater than the control speakers. Therefore HJ demonstrates spatial but not temporal consistency.

6.2.8.10 HL (anomic)

Productions from this speaker appear consistent with respect to duration and the temporal relationship between the /t/ and /k/ (see Graph 6-30). ASC for all repetitions are between 40 and 70 milliseconds from the reference point. Distances between ASR and SCEA range between 10 milliseconds and 50 milliseconds. Whilst this is greater than the control speakers the durations are considerable shorter than some of the other aphasic speakers. The duration of the alveolar stop closure appears of increased length compared to the normal data.

6.2.9 Spatial details of successive repetitions as seen from the EPG trace

The frame indicating the onset of velar closure (SCEA) is shown for each speaker except JM, who consistently omitted the velar, in Figure 6-15 and Figure 6-16. MU only produced seven repetitions where this point was identifiable. Since the spatial patterns for the /k/ are likely to be affected when the /t/ is assimilated the VI was not calculated.

Despite the production of different sequencing patterns the lingual/palatal contact patterns for all speakers are characterized by a horse shoe shape involving the velar portion of the palate and varying degrees of the lateral margins. The degree of lateral contact appears to be dependent on the amount of alveolar contact. Three of the control speakers (KM, LD, and SN) show no alveolar contact compared to only one of the aphasic speakers (IE). Double alveolar/velar articulations are produced by seven control speakers (AM, FG, JS (partial), LE, PR, WH and WJ) and five aphasic speakers (FM, MU, CR, PW and FC). The shading indicates that this is a consistent feature for FG and PR (control speakers) but no aphasic subject. The alveolar contacts for the /t/ during double alveolar/velar articulation often appear retracted so many contacts are actually realized in the palatal region. MU's lingual/palatal contact patterns involve more of the palatal region (rows 3, 4 and 5) than any of the other speakers.

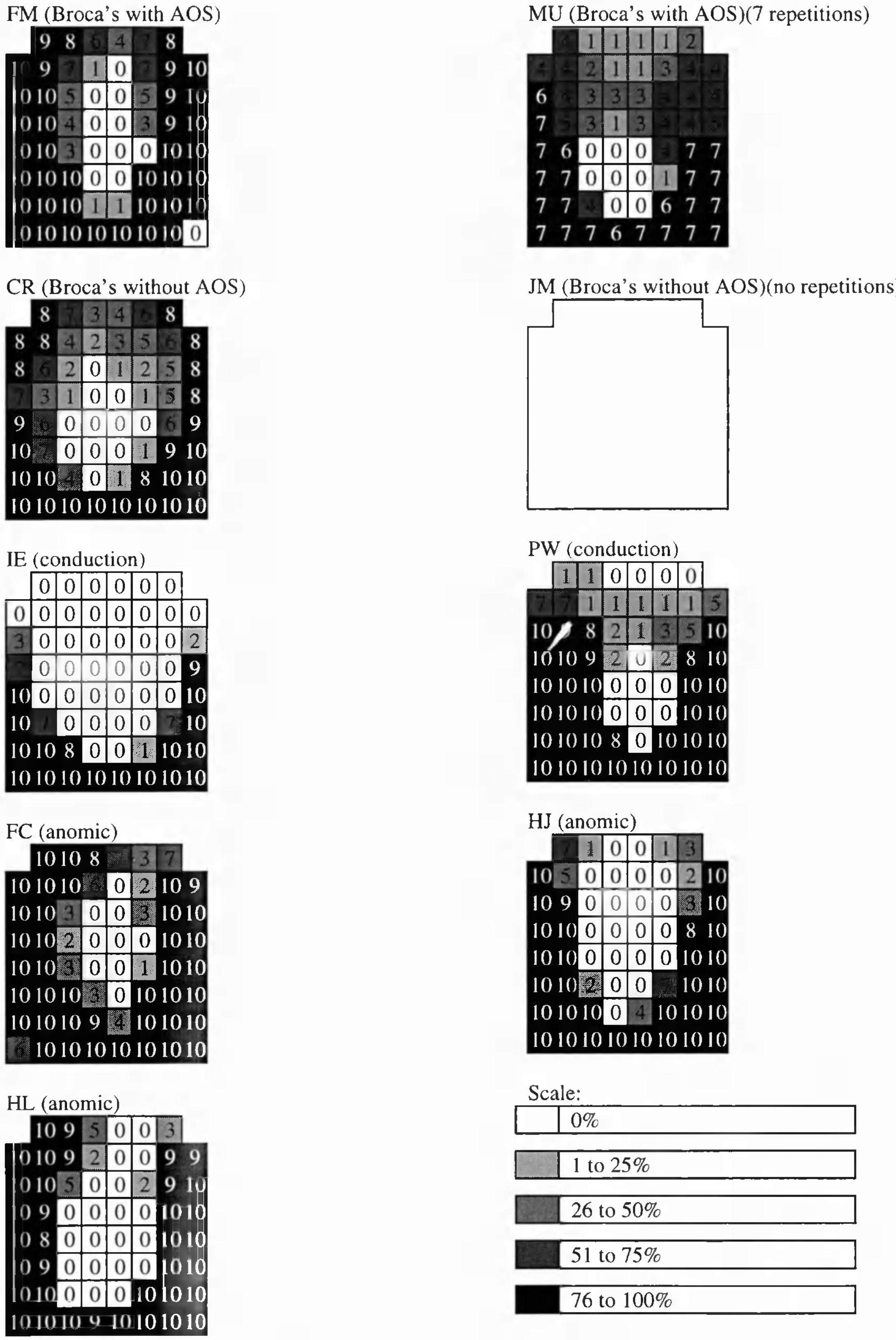


Figure 6-15: Prototypical frame indicating the onset of velar closure over 10 repetitions (SCEA) for aphasic speakers.

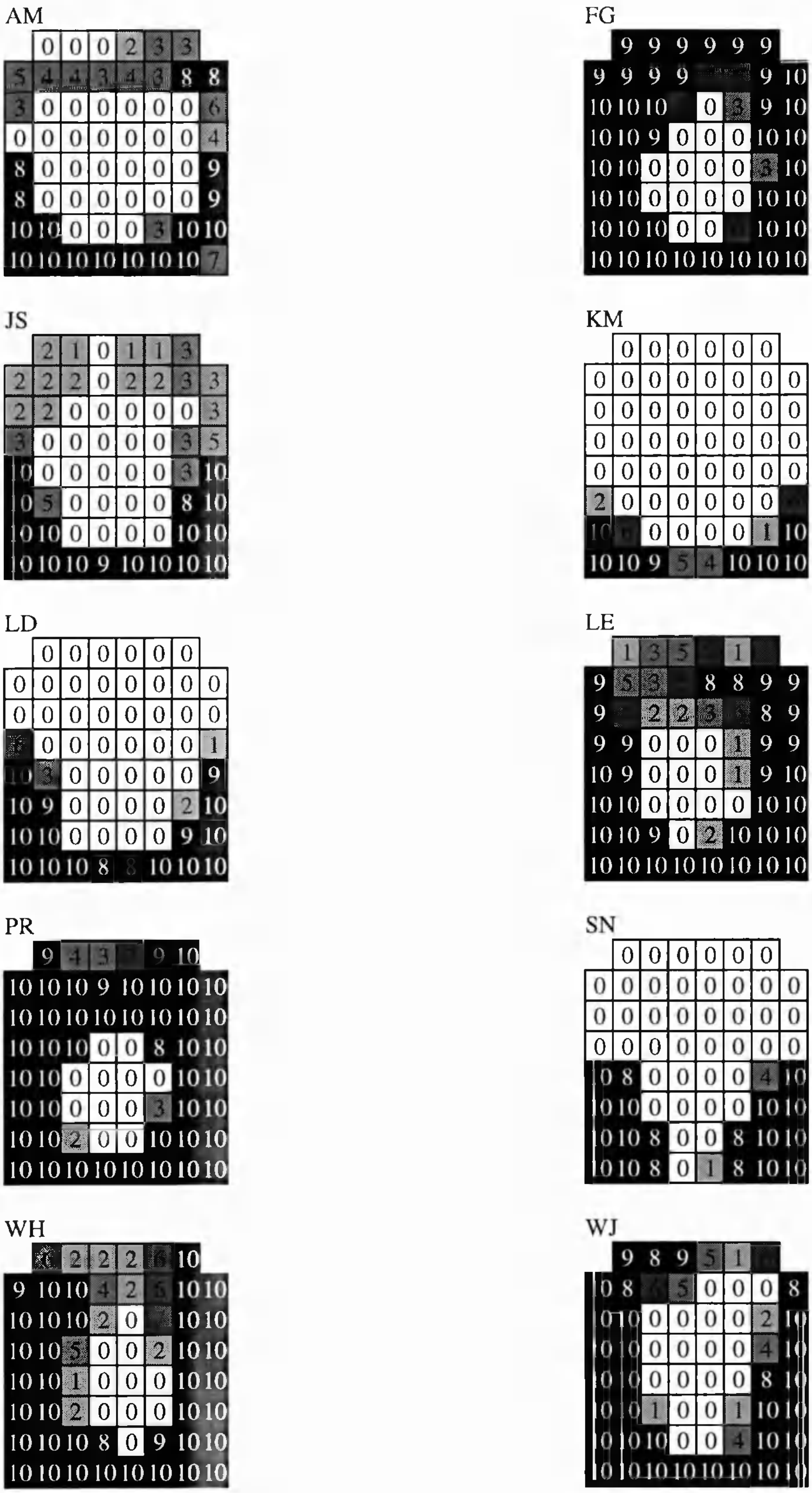


Figure 6-16: Prototypical frame indicating the onset of velar closure over 10 repetitions (SCEA) for control speakers.

6.2.10 Summary of results

The following is a summary of the main points arising from analysis of repetitions of the WI /kl/ and the WM /tk/ sequences in "clock" and "kitkat" respectively.

6.2.10.1 Variability of sequencing patterns for /kl/

1. Sequencing patterns identified by Hardcastle (1985) from the speech of non-neurologically impaired subjects do not adequately describe the sequencing patterns produced by the aphasic speakers. Additional sequencing patterns are needed to account for reversal and omission of phonemes and MAGs.
2. Both control and aphasic speakers produce type 1 patterns (release of the /k/ prior to onset of tongue tip/blade) more frequently than other patterns.
3. Omission of a phoneme by aphasic speakers occurs during 34.4% of productions.
4. /l/ is more frequently omitted than /k/ (31.1% and 3.3% respectively).
5. MAGs are only evident when a phoneme in the /kl/ sequence is omitted.
6. The mean duration between gestures for productions where the velar is released prior to the onset of the tongue tip/blade movement (type 1 pattern) is 80msecs for control and 90msecs for aphasic speakers.
7. The control group use either type 1 or type 2 sequencing patterns indicating little intra-subject variability.
8. Three of the aphasic speakers (FM, Broca's with AOS; CR, Broca's without AOS; FC, anomic aphasic) demonstrate more than two sequencing patterns over ten successive repetitions.
9. Aphasic productions become less variable over successive repetitions.

6.2.10.2 Spatial variability of /kl/sequences

1. Five aphasic speakers (MU and FM, Broca's with AOS; CR, Broca's without AOS; FC and HJ, anomic aphasics) have VI scores which are +1 standard deviation above the mean VI score calculated for the control group.
2. The aphasic groups VI scores are statistically more variable than the control group.
3. Increased variability is not related to the aphasic syndrome but subject specific.
4. Conduction aphasics as a group show VI scores which are within +1 standard deviations of the mean VI score for control speakers.

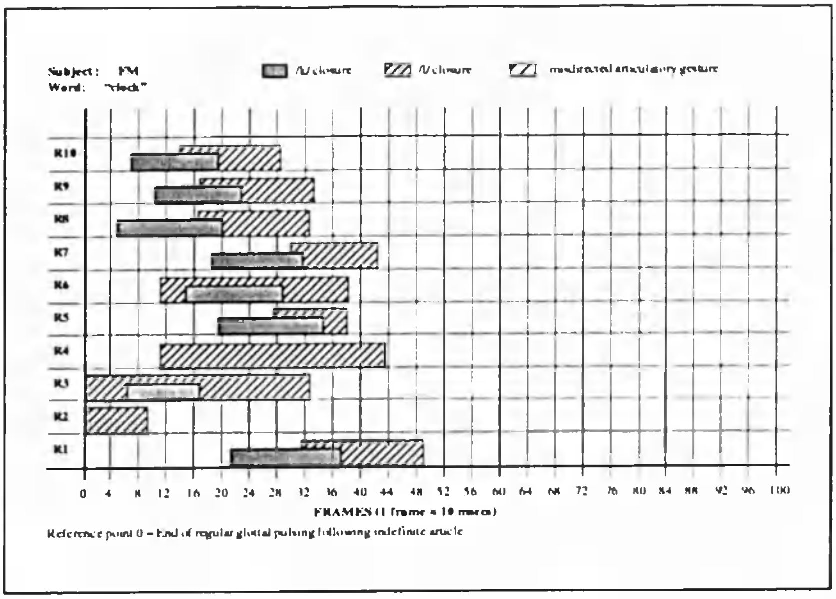
6.2.10.3 Variability of sequencing patterns for /tk/

1. The aphasic group produce more sequencing patterns than the control group. The additional patterns indicate errors in sequencing.
2. The most common sequencing pattern for the control group is the assimilation of the /t/ to the velar place of articulation (47%). This sequencing pattern was noted during 8.9% of aphasic productions.
3. The most common sequencing pattern for the aphasic group is the release of the /t/ prior to the /k/ (54.4%). This sequencing pattern was noted during 16% of the control speakers productions.

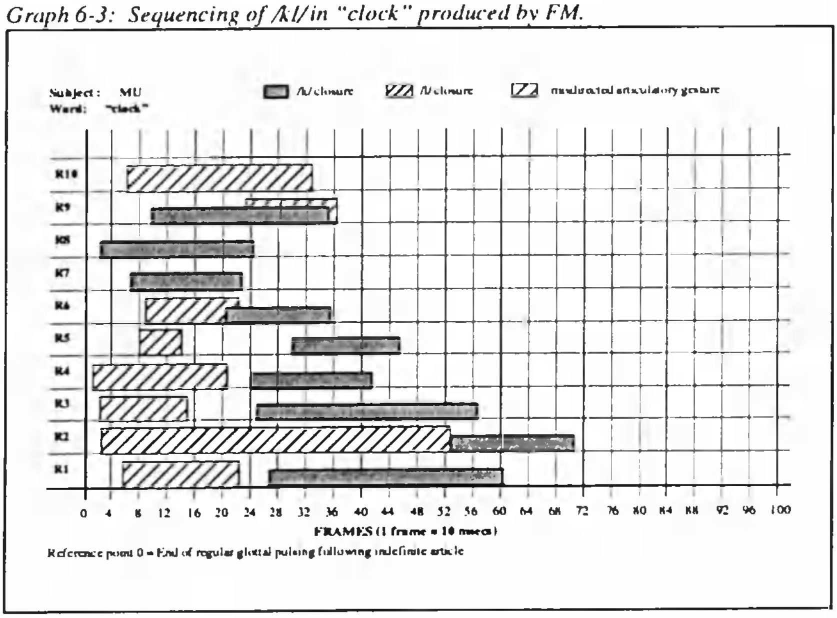
4. There is some consistency within the aphasic syndromes for the type of sequencing pattern favoured. Both conduction and anomic speakers productions are characterized by a type 1 sequencing pattern (release of the /t/ closure prior to full velar closure) during 92% of their productions.

5. The aphasic speakers demonstrate less variability in the choice of sequencing patterns used for WM /tk/ than the in WI /kl/.

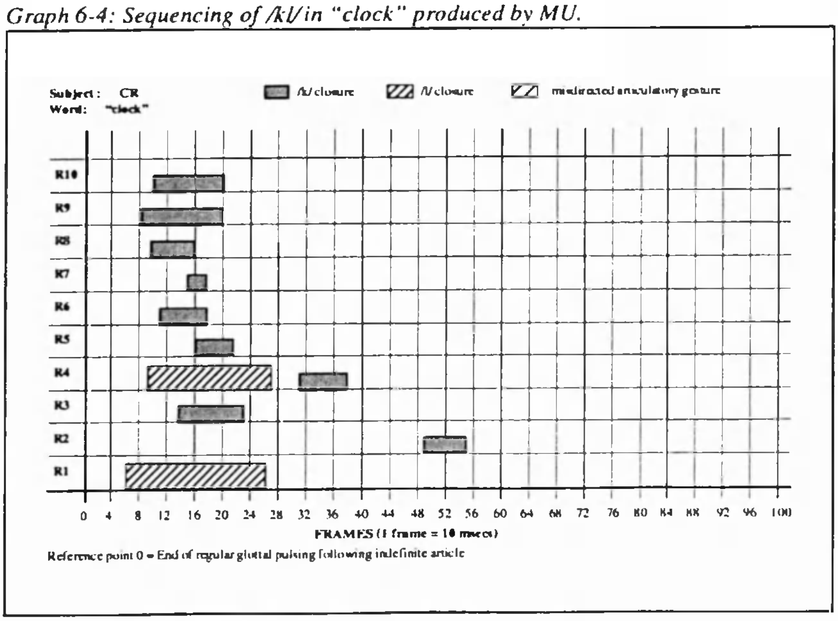
6. The aphasic speakers productions become more consistent over successive repetitions.



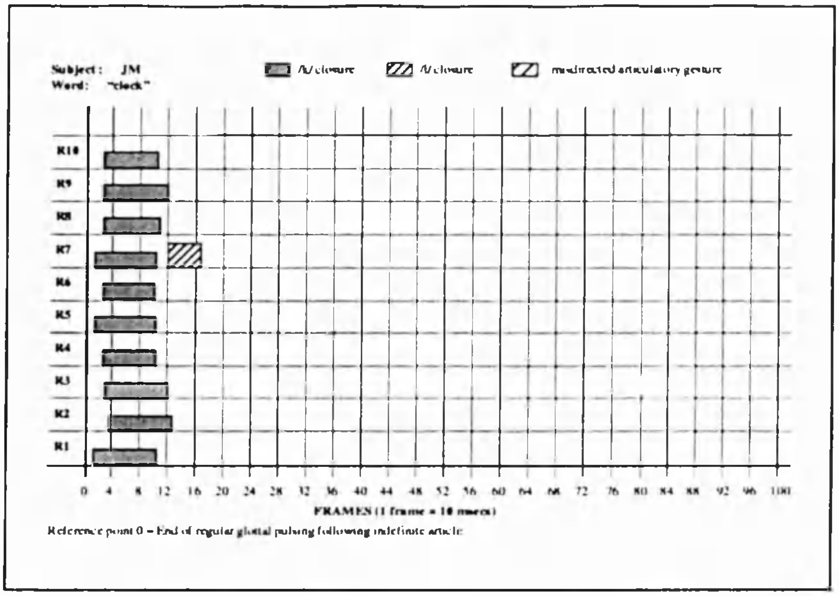
Graph 6-3: Sequencing of /kl/ in "clock" produced by FM.



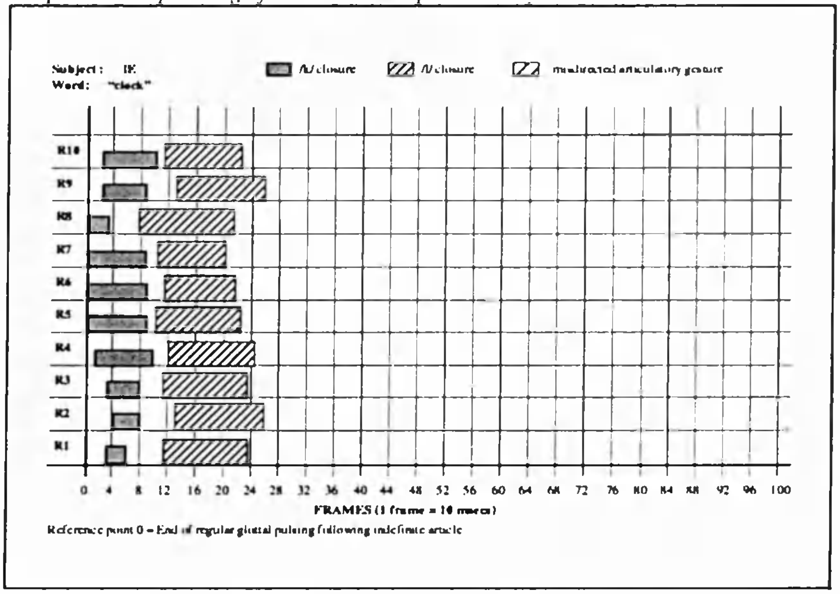
Graph 6-4: Sequencing of /kl/ in "clock" produced by MU.



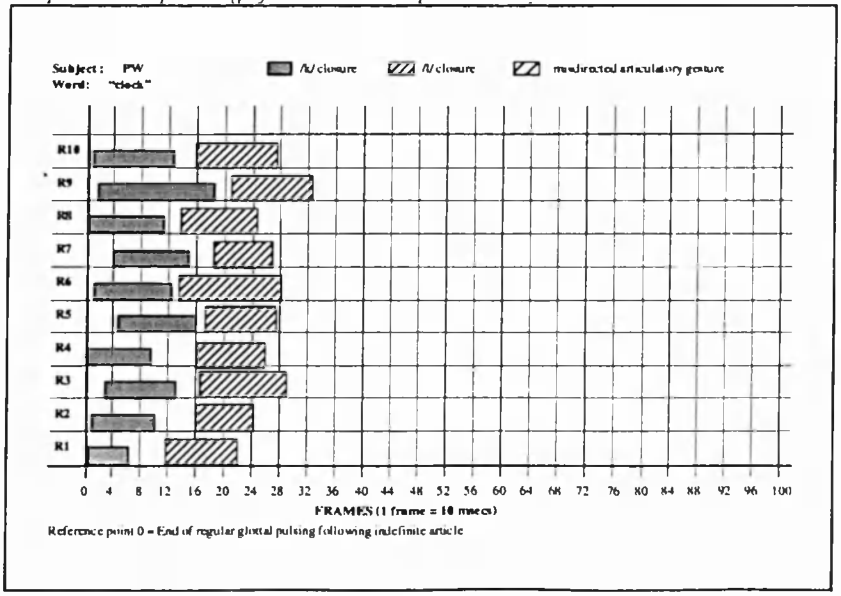
Graph 6-5: Sequencing of /kl/ in "clock" produced by CR.



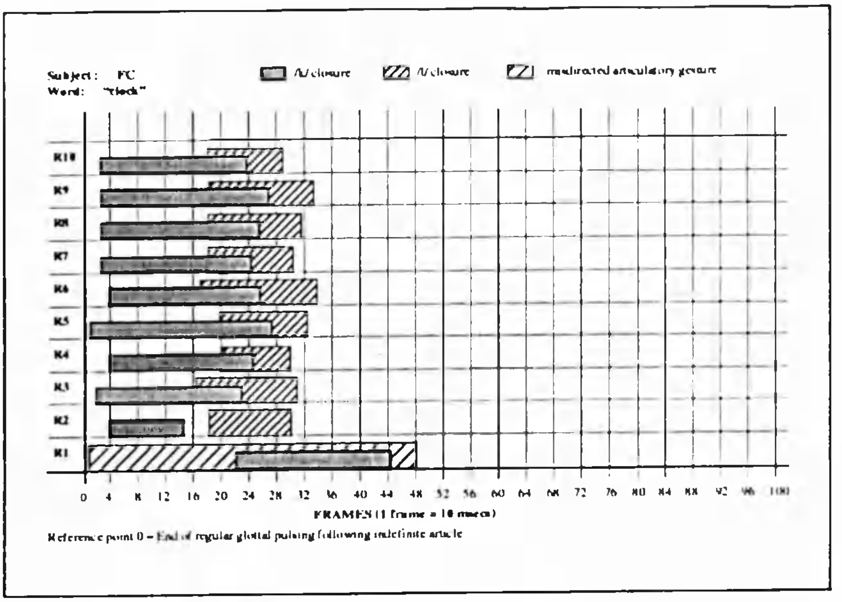
Graph 6-6: Sequencing of /kl/ in "clock" produced by JM.



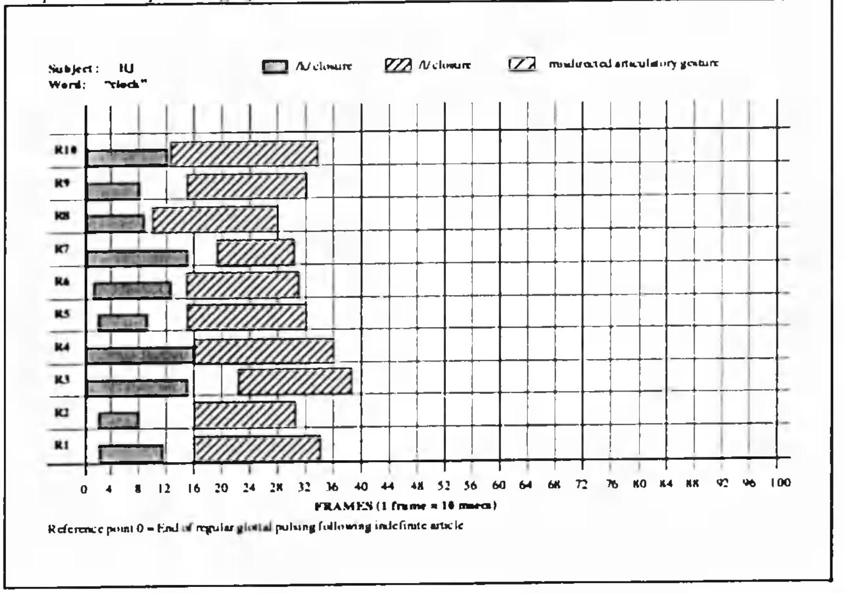
Graph 6-7: Sequencing of /kl/ in "clock" produced by IE.



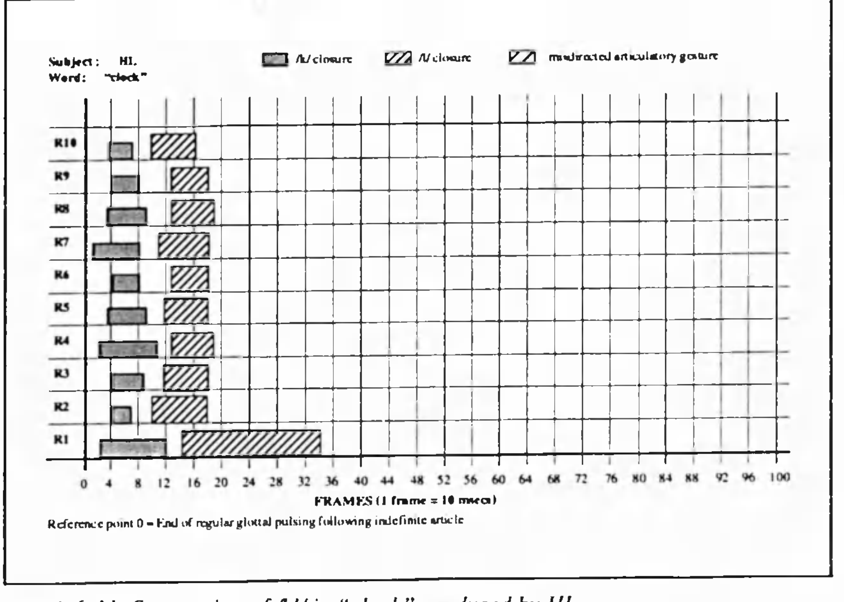
Graph 6-8: Sequencing of /kl/ in "clock" produced by PW.



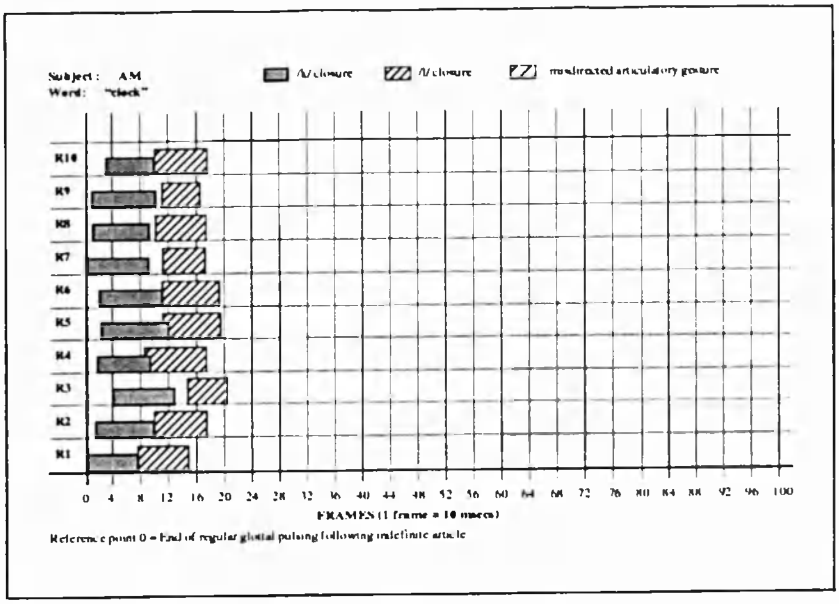
Graph 6-9: Sequencing of /kl/ in "clock" produced by FC.



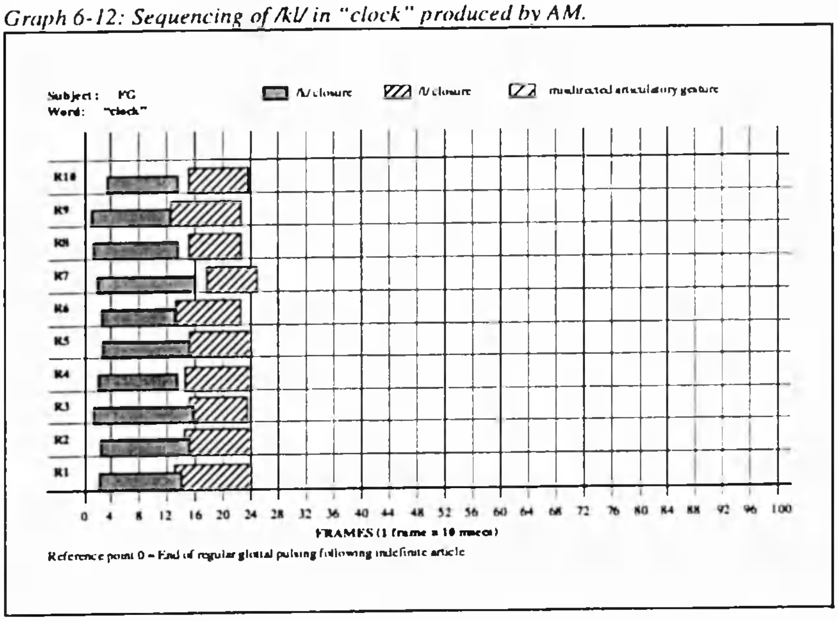
Graph 6-10: Sequencing of /kl/ in "clock" produced by HJ.



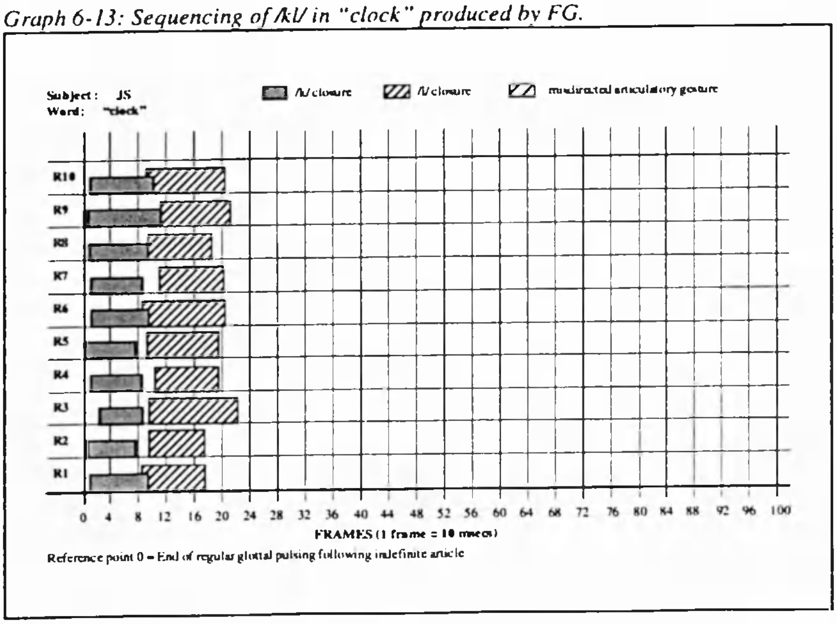
Graph 6-11: Sequencing of /kl/ in "clock" produced by HL.



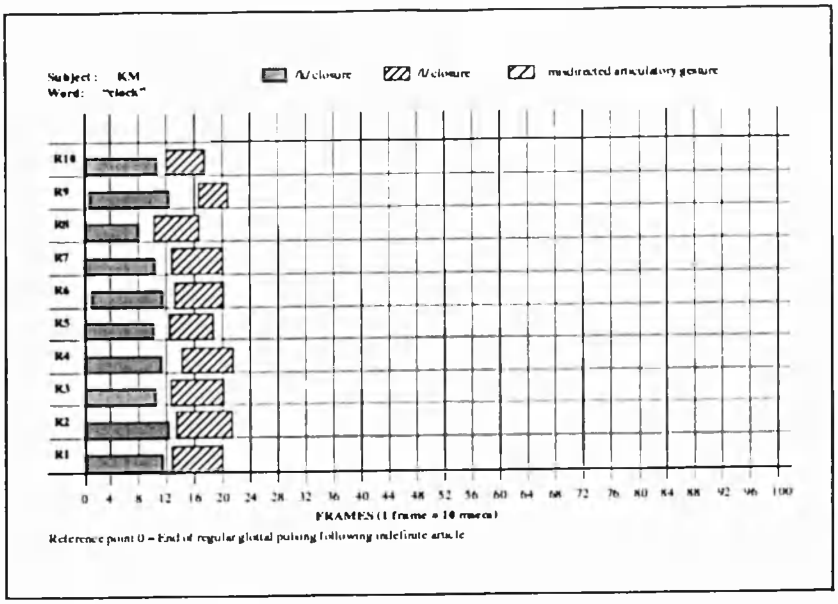
Graph 6-12: Sequencing of /kl/ in "clock" produced by AM.



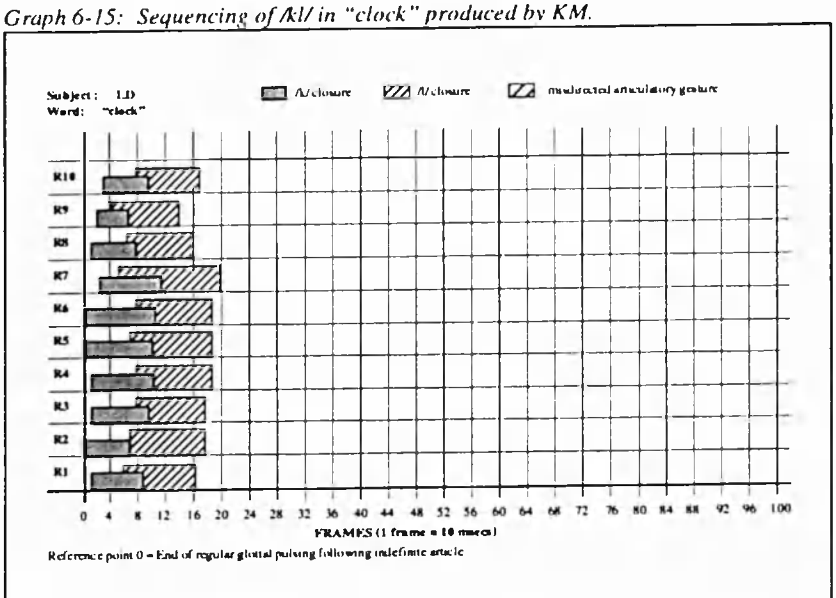
Graph 6-13: Sequencing of /kl/ in "clock" produced by FG.



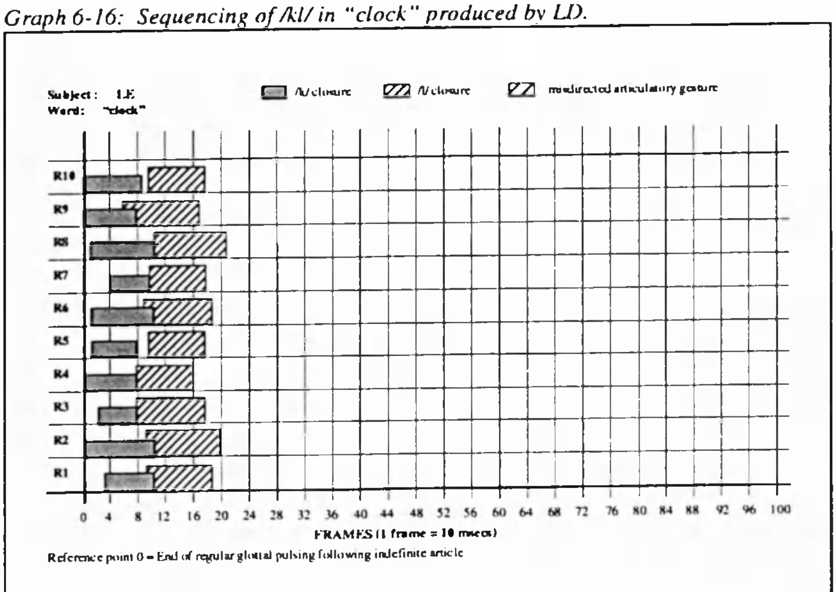
Graph 6-14: Sequencing of /kl/ in "clock" produced by JS.



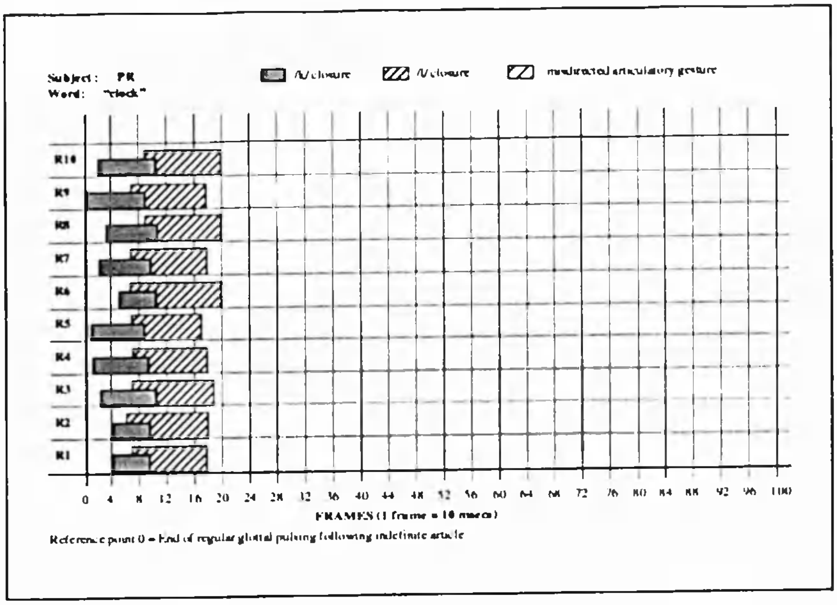
Graph 6-15: Sequencing of /kl/ in "clock" produced by KM.



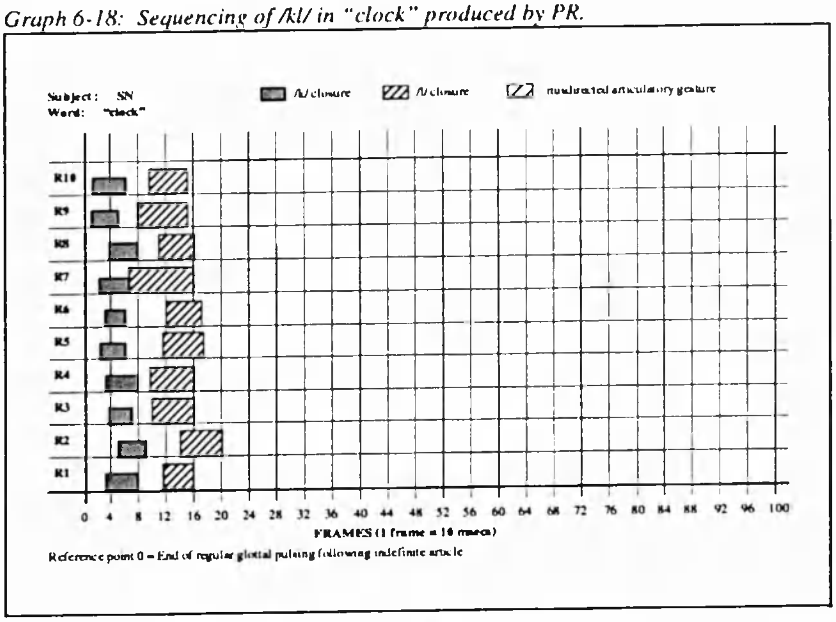
Graph 6-16: Sequencing of /kl/ in "clock" produced by LD.



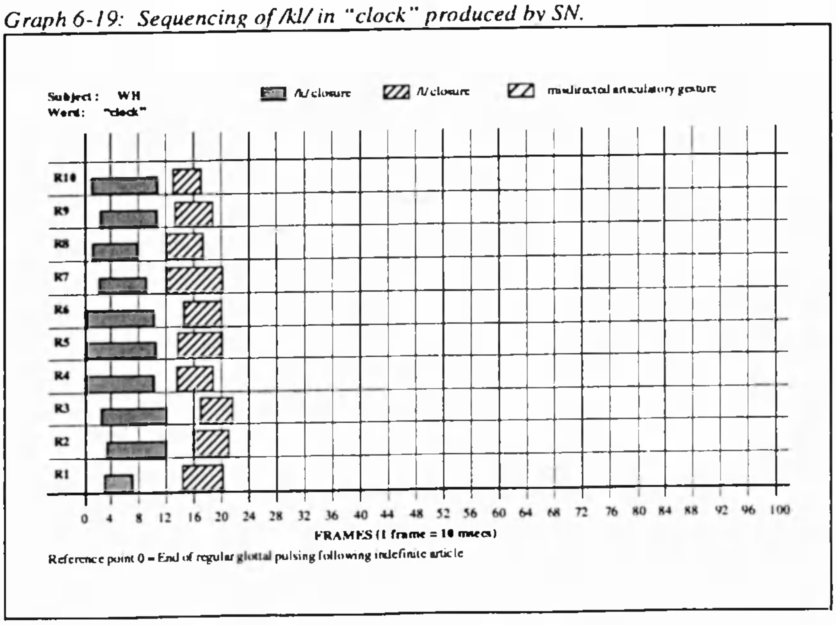
Graph 6-17: Sequencing of /kl/ in "clock" produced by LE.



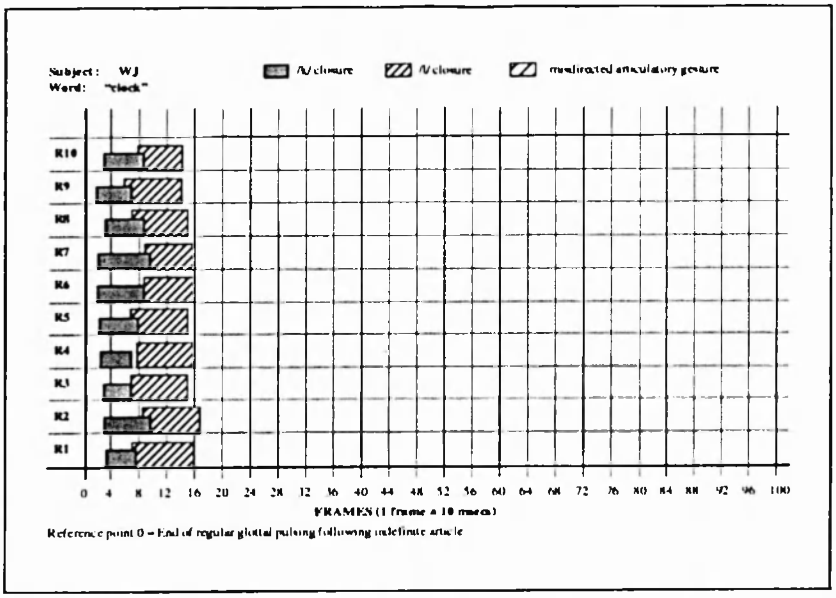
Graph 6-18: Sequencing of /kl/ in "clock" produced by PR.



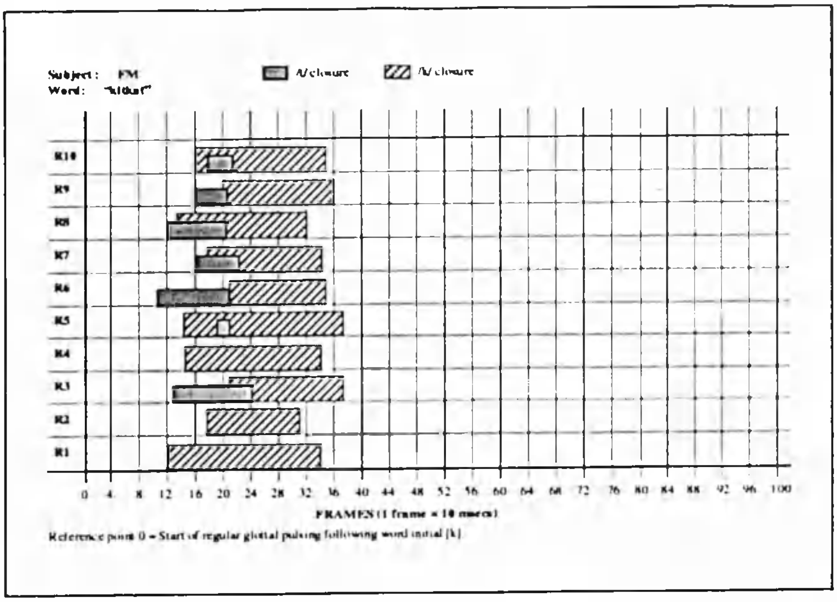
Graph 6-19: Sequencing of /kl/ in "clock" produced by SN.



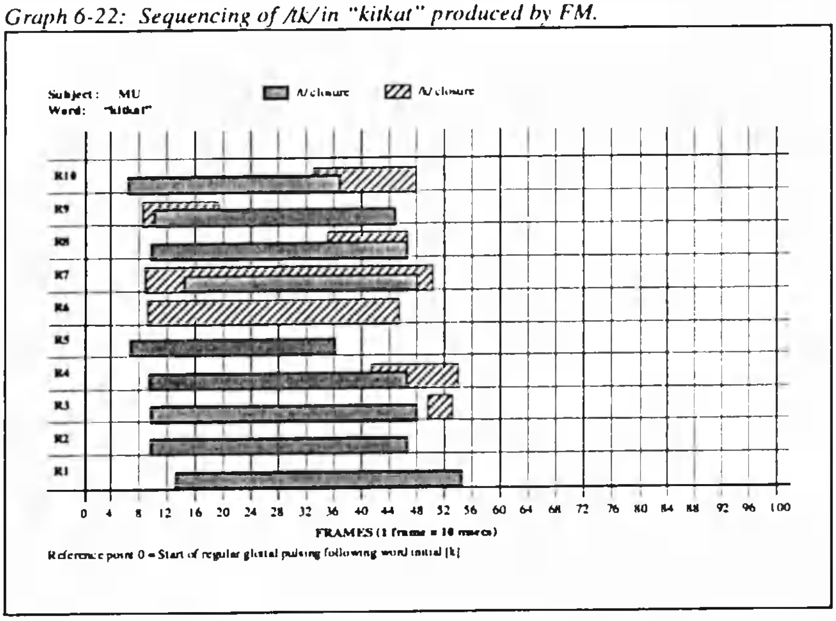
Graph 6-20: Sequencing of /kl/ in "clock" produced by WH.



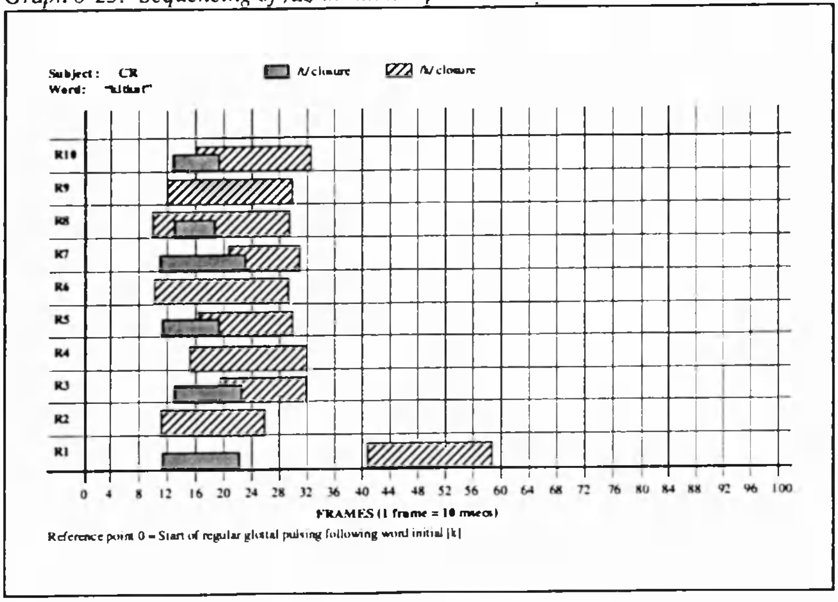
Graph 6-21: Sequencing of /kl/ in "clock" produced by WJ.



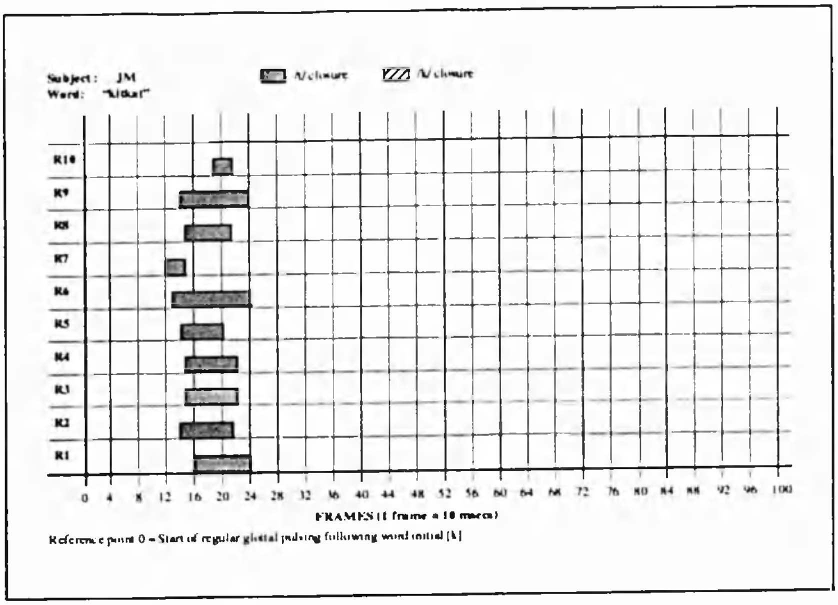
Graph 6-22: *Sequencing of /tk/ in "kitkat" produced by FM.*



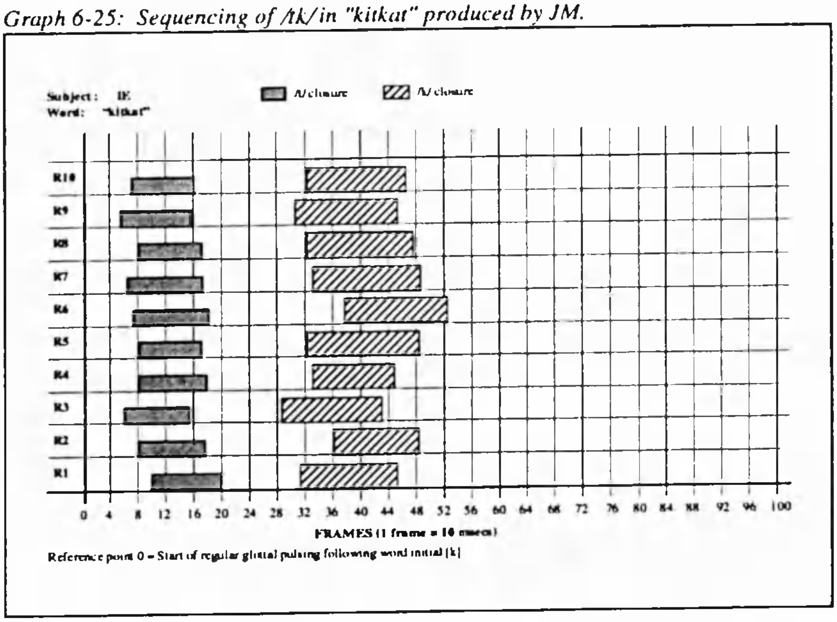
Graph 6-23: *Sequencing of /tk/ in "kitkat" produced by MU.*



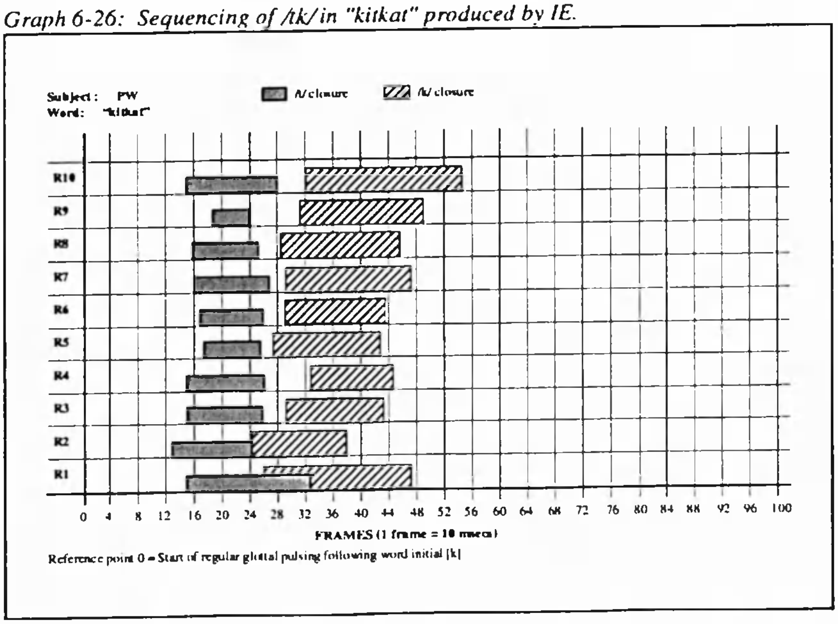
Graph 6-24: *Sequencing of /tk/ in "kitkat" produced by CR.*



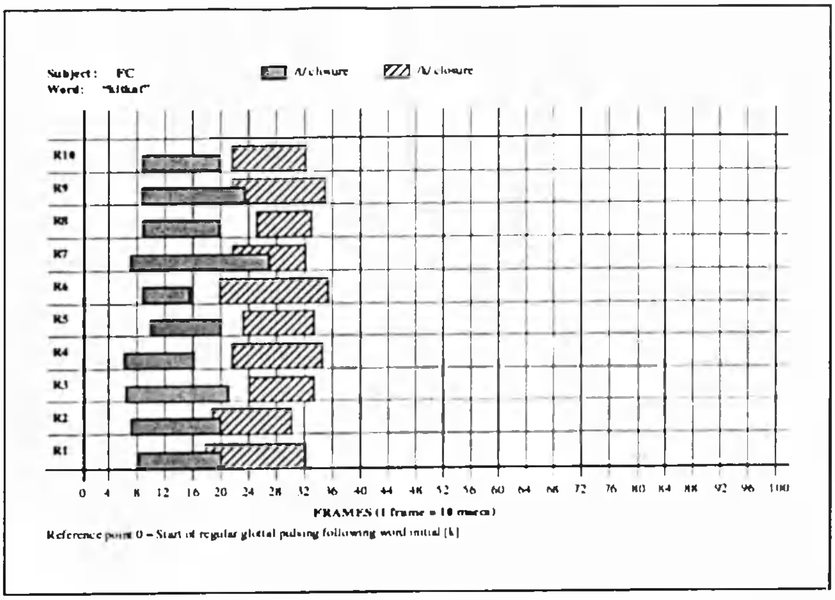
Graph 6-25: Sequencing of /tk/ in "kitkat" produced by JM.



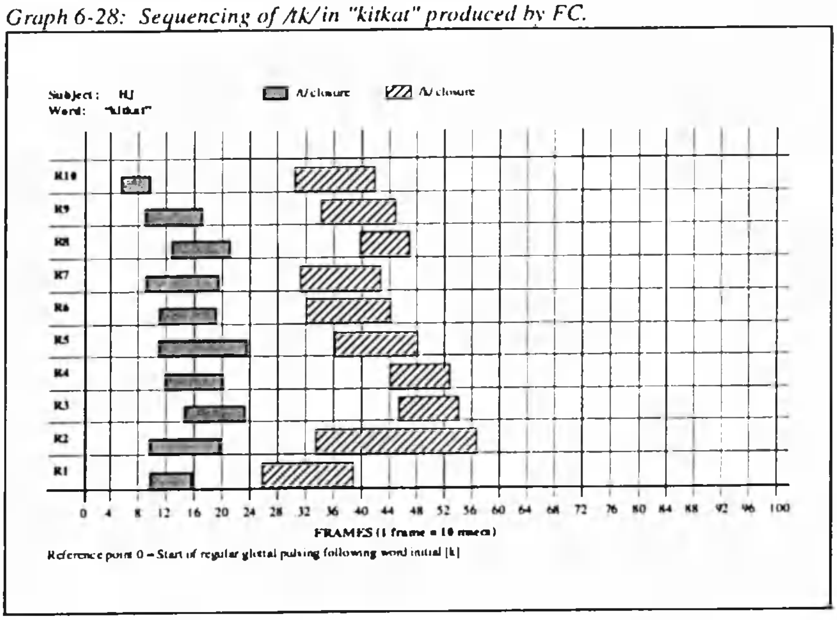
Graph 6-26: Sequencing of /tk/ in "kitkat" produced by IE.



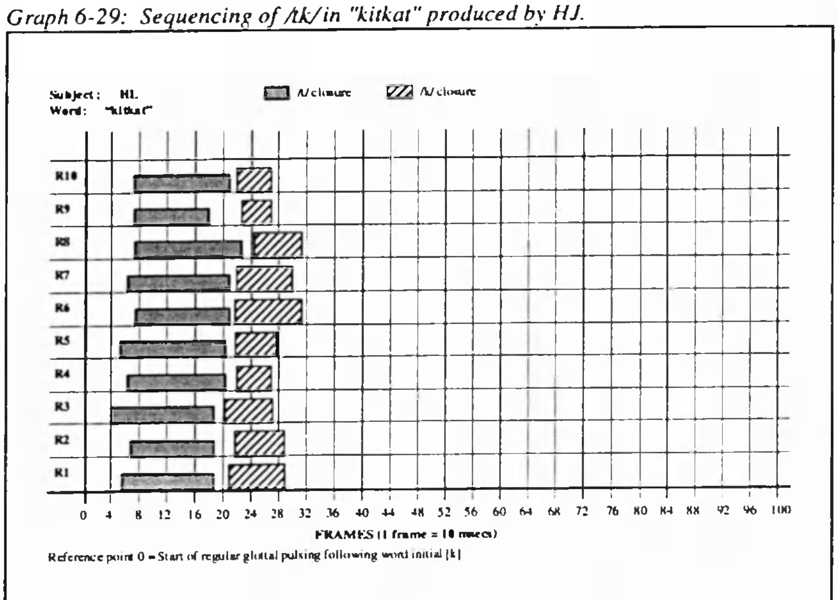
Graph 6-27: Sequencing of /tk/ in "kitkat" produced by PW.



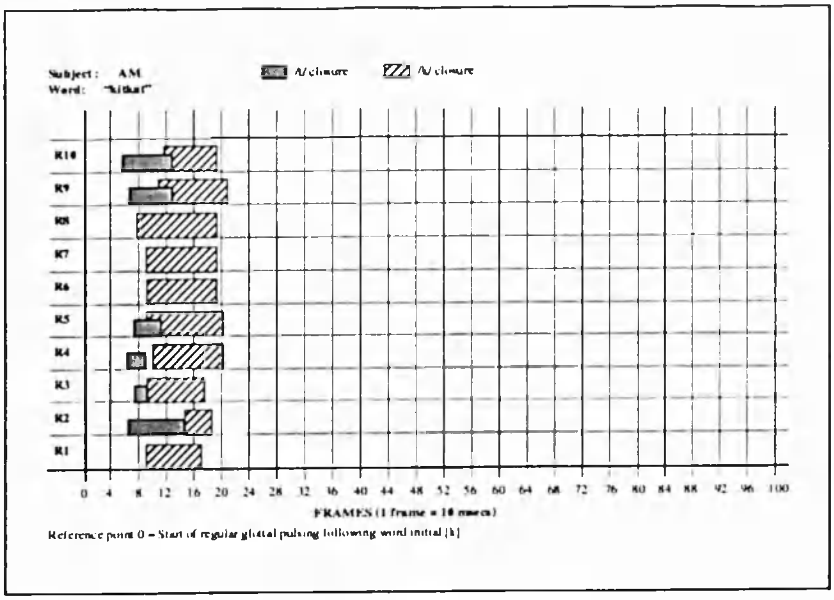
Graph 6-28: Sequencing of /tk/ in "kitkat" produced by FC.



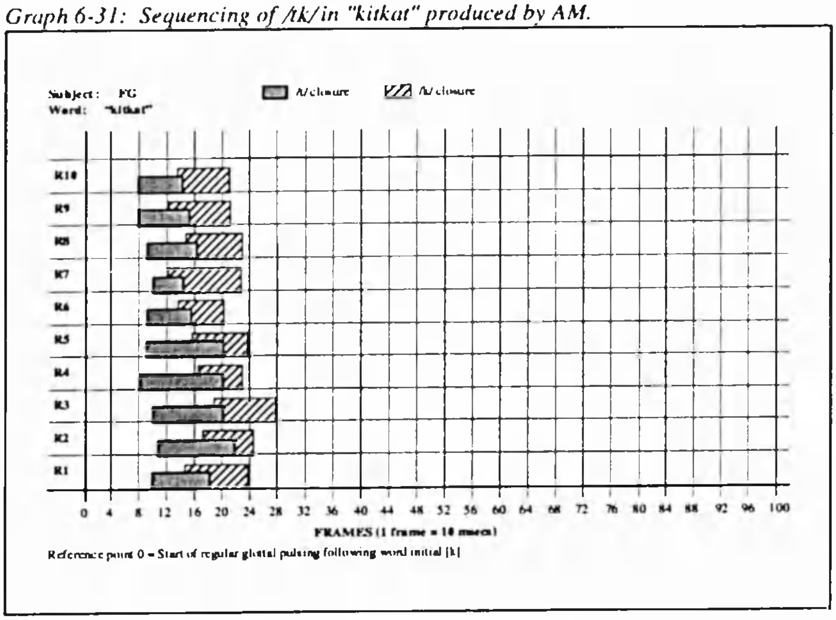
Graph 6-29: Sequencing of /tk/ in "kitkat" produced by HJ.



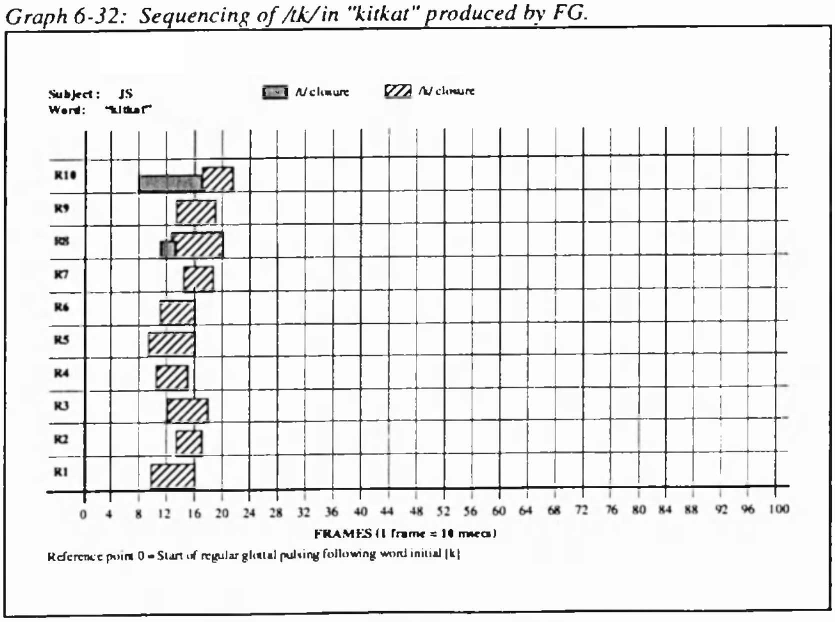
Graph 6-30: Sequencing of /tk/ in "kitkat" produced by HL.



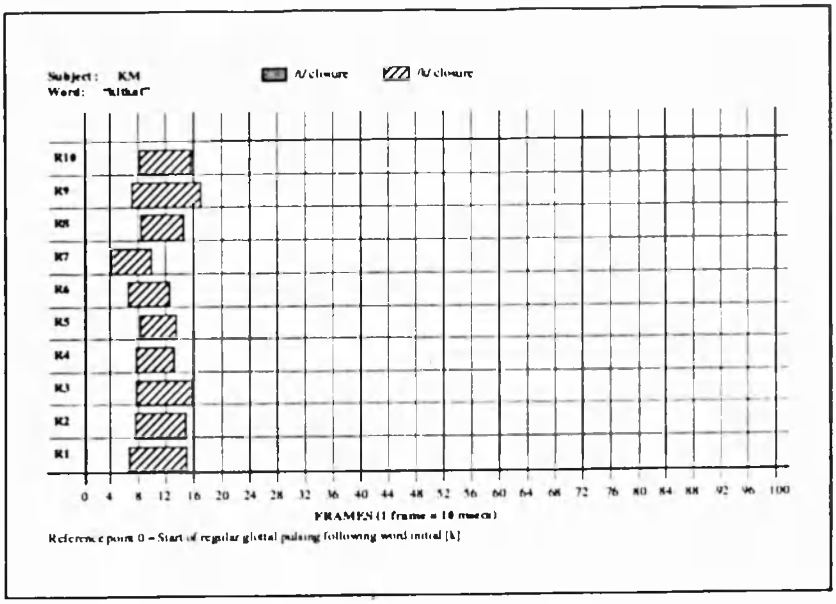
Graph 6-31: Sequencing of /tk/ in "kitkat" produced by AM.



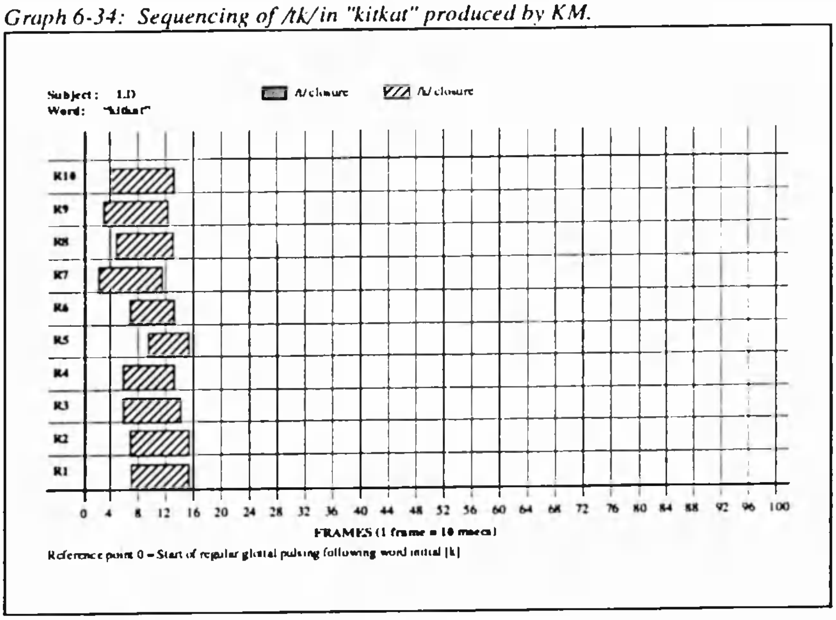
Graph 6-32: Sequencing of /tk/ in "kitkat" produced by FG.



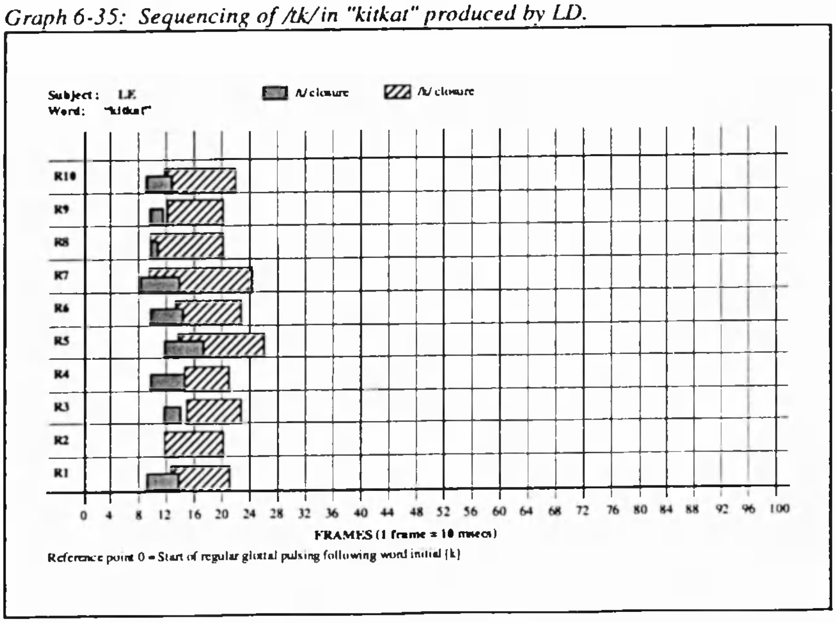
Graph 6-33: Sequencing of /tk/ in "kitkat" produced by JS.



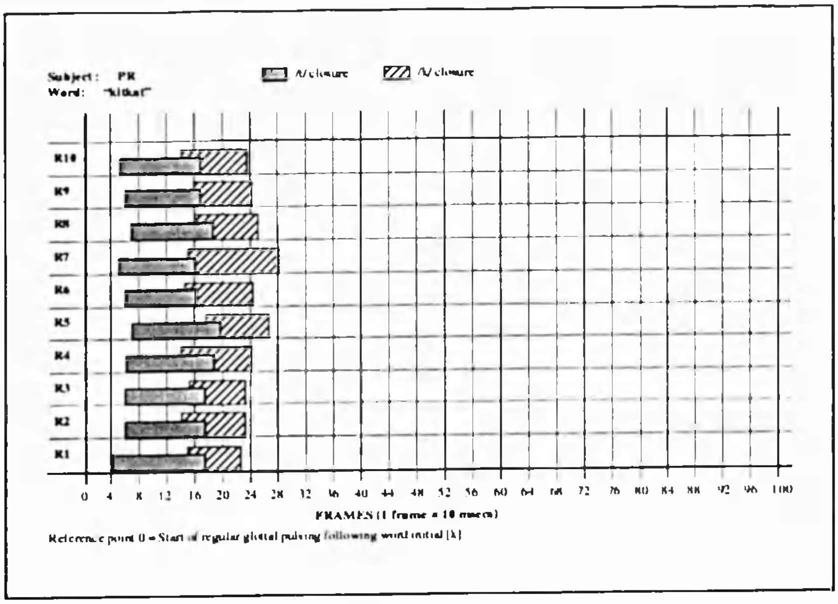
Graph 6-34: Sequencing of /tk/ in "kitkat" produced by KM.



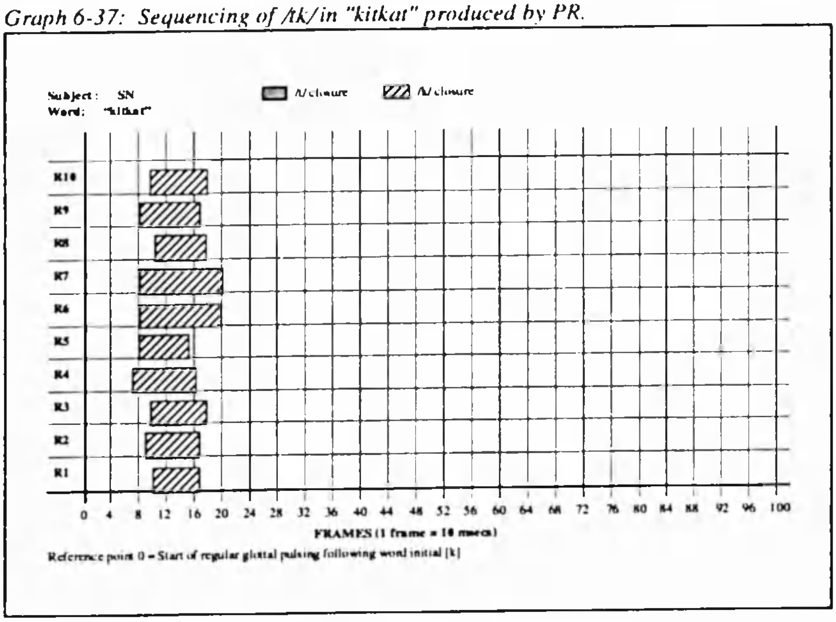
Graph 6-35: Sequencing of /tk/ in "kitkat" produced by LD.



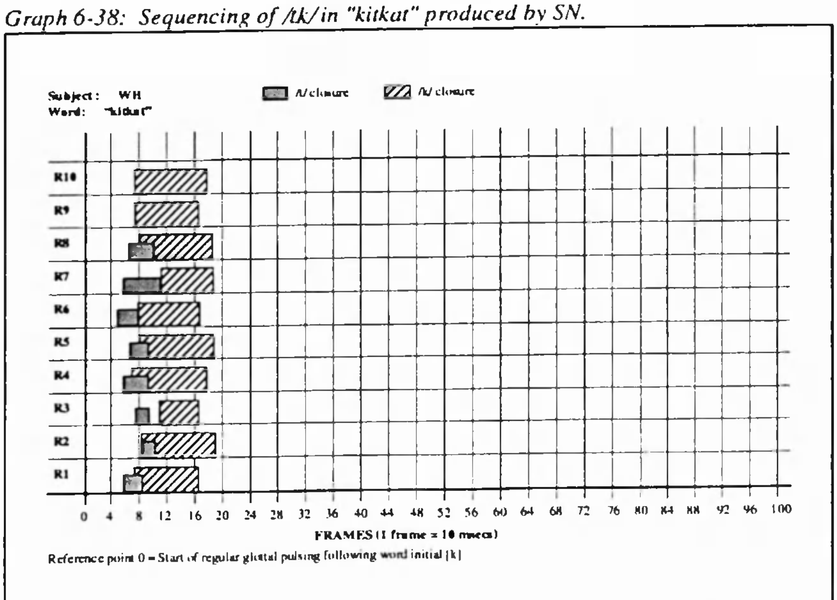
Graph 6-36: Sequencing of /tk/ in "kitkat" produced by LE.



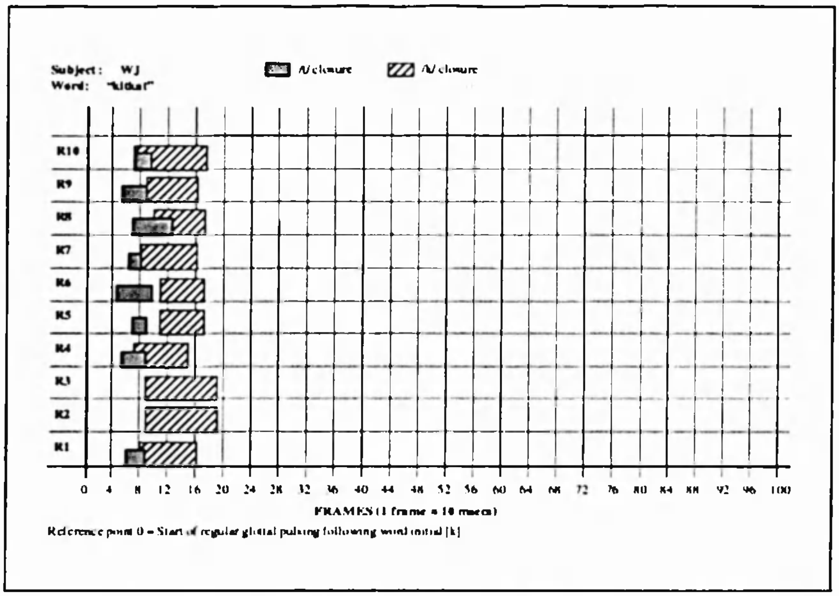
Graph 6-37: Sequencing of /tk/ in "kitkat" produced by PR.



Graph 6-38: Sequencing of /tk/ in "kitkat" produced by SN.



Graph 6-39: Sequencing of /tk/ in "kitkat" produced by WH.



Graph 6-40: Sequencing of /tk/ in "kitkat" produced by WJ.

Chapter 7

7. Results 3: Misdirected Articulatory Gestures (MAGs)

7.1 Introduction

In their description of apraxic based speech errors, Hardcastle and Edwards (1992) identified six different error types produced consistently by four apraxic speakers. Of particular interest in this study are those errors which were labelled "misdirected articulatory gestures". These were defined as gestures which were spatially normal but that occurred in an inappropriate place in the target utterance. The most frequent pattern was an alveolar/velar double articulation which usually appeared in word initial position. These had been previously noted by Hardcastle (1985) in the speech of an apraxic subject. Typically the misdirected gesture occurred during production of a word initial alveolar stop closure, for example the initial /d/ in "deer", "dolls" and "dart" (see Figure 7-1). These double articulations were also observed, albeit less often, during word initial fricatives ("zoo", "sheep"). Hardcastle and Edwards (1992) noted that the double articulations in "deer", "dolls" and "dart" were "most frequently ..... identified as a normal alveolar stop" (p.323) through phonetic transcription and therefore the misdirected velar gesture was unheard. However, if the velar gesture was released after the alveolar this was generally heard. An example of a velar MAG produced by an apraxic speaker (BT) from an earlier study by Hardcastle (1985) can be seen in Figure 7-1. The target gesture /d/ is preceded by full velar closure commencing at frame 0598. Full alveolar closure starts at frame 0606, overlapping with the velar articulation. Therefore a period of double velar/alveolar articulation results. In this example the velar MAG was variously detected through auditory analysis as either [gdiə] or [diə].

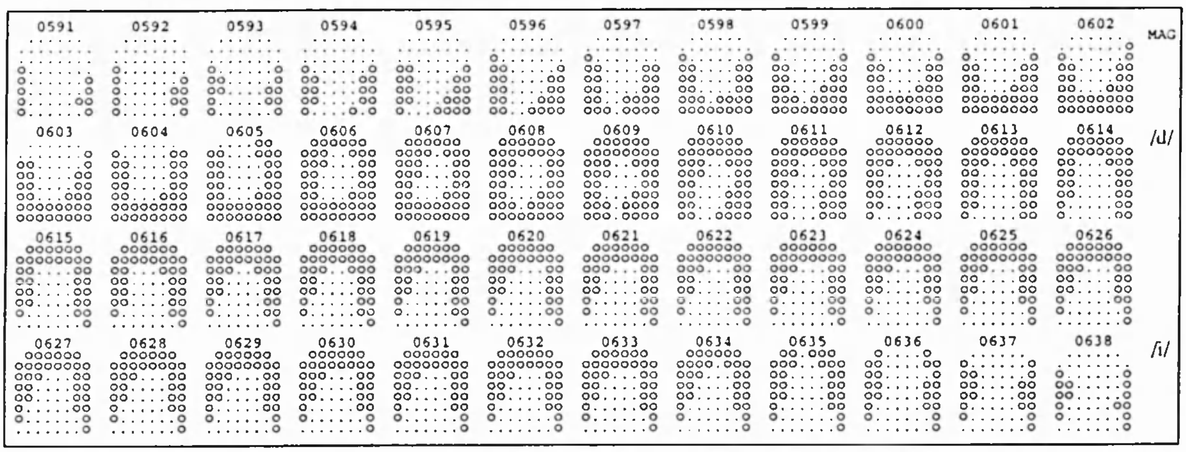


Figure 7-1: WI misdirected velar gesture produced by BT during production of the word "deer" variously transcribed as [gdiə] or [diə]. Taken from Hardcastle, 1985 (p.258).

Sugishita et al. (1987) also identified misdirected gestures which were not detected through auditory analysis in their investigation of omission errors in one left handed and one right handed apraxic speaker. On analysis of the EPG data they identified lingual/palatal contacts during perceived omissions. Sometimes the correct articulation had been made but not heard, on others incorrect lingual/palatal contacts were detected through auditory analysis. These were similar to those identified by Hardcastle and Edwards (1992) and classified as MAGs since the contact patterns were spatially normal. But unlike Hardcastle and Edwards who detected intrusive velar gestures, Sugishita et al. (1987) identified alveolar stop patterns.

These types of errors are felt to be important since they may provide valuable information regarding the source of the error. In particular, analysis of the lingual/palatal contact patterns and the relationship that the misdirected gesture holds with other target phonemes in the word may help in identifying whether the error is linguistic or motoric in origin or indeed both.

In this investigation, articulations from production of word lists A and B plus the repetition task were analysed in detail to identify any MAGs. Since the target lingual/palatal contact patterns were known, the source of any errors identified can be speculated. A total of 122 words were analysed for each subject (MU 91 words; BA 92 words). These words were initially phonetically transcribed using IPA symbols (revised to 1993) and then the lingual/palatal contact patterns were analysed to identify any MAGs. Any words where a MAG was noted were then compared to the phonetic transcriptions to determine whether these were detected auditorily or not. The phonetic transcriptions for each subject are given in Appendix A.

Of the ten aphasic subjects investigated analysis of the EPG data revealed that eight subjects made MAGs (not JM, Broca's with AOS, nor HJ, anomic). These will now be considered in more detail.

7.2 Incidence And Type Of Misdirected Articulatory Gesture

Of the eight aphasic speakers who produced intrusive lingual/palatal contacts, six produced misdirected alveolar gestures, seven produced misdirected velar gestures and two produced misdirected double articulations (see Table 7-1). Double articulation MAGs were considered separate from alveolar MAGs and velar MAGs. They were defined as articulations where neither an alveolar nor a velar phoneme were the target gestures but where both were seen with a period of overlap on analysis of the EPG data. For example, a double alveolar/velar articulation occurring in WI position where the target phoneme was a bilabial, as in "book", was considered separate to a double alveolar/velar articulation in WI position where the target phoneme was either an alveolar (e.g. "tip") or velar (e.g. "car").

All the MAGs were considered to be completely different from pure substitutions (paraphasias), that is errors detected through auditory analysis (e.g. "key" → [tʰi]) with normal lingual/palatal contacts for the substituted sound only. MAGs were defined as productions where either a substitution, distortion or correct articulation was detected through auditory analysis but inspection of the EPG data revealed additional lingual/palatal contacts. Also included in the definition were errors such as the example in Figure 7-1 where an additional gesture(s) was seen from the EPG data and where both were sometimes detected through auditory analysis (e.g. [gdiə]).

Subjects	Diagnosis	Misdirected articulatory gestures (MAGs)				
		Alveolar	Velar	Double alveolar/velar	Total	%tage
FM	Broca's with AOS	0	1		1	0.8
MU	Broca's with AOS	36	4	1	41	33.6
BA	Broca's without AOS	2	1		3	3.3
CR	Broca's without AOS	5	4		9	7.4
JM	Broca's without AOS	0	0		0	0
IE	conduction	10	4	1	15	12.3
PW	conduction	3	0		3	3.3
FC	anomic	0	2		2	1.6
HJ	anomic	0	0		0	0
HL	anomic	1	2		3	3.3
Total		57	18	2	77	

Table 7-1: Incidence and type of intrusive articulatory gestures for all aphasic subjects. Where neither an alveolar or velar articulation was the target phoneme but both an alveolar and a velar were produced the MAG was marked as a double alveolar/velar gesture. %tage indicates the percentage of the target words where a MAG was detected.

The incidence of MAGs varied considerably between the aphasics and appeared to be subject specific and not a feature of a particular aphasia syndrome. For example, MU diagnosed as a Broca's aphasic with AOS, produced a total of 41 MAGs compared to only 1 produced by FM who has the same speech diagnosis. Similarly, JM, who is diagnosed as a Broca's aphasic without AOS, produced no MAGs but CR who has the same diagnosis produced 9.

Misdirected alveolar gestures were far more frequent than velar, alveolars occurring over three times more often. Of these MAGs approximately 25% were identified through auditory analysis. The majority of MAGs were identified in word initial position (Table 7-2).

Word position	Misdirected articulatory gestures (MAGs)		
	Alveolar	Velar	Double alveolar/velar
Word initial position (WI)	47	16	2
Word medial position (WM)	5	2	0
Word final position (WF)	5	0	0

Table 7-2: Position of MAGs in the word.

All bar two velar gestures and 82% (47/57) of the alveolar gestures occurred in WI position. Of the 57 alveolar MAGs 30% (17/57 words) occurred where there was a target alveolar plosive or nasal in the word (/t, d, n/). For velar MAGs the incidence of words where there was a target velar plosive (/k,g/) in the word was much greater at 72% (13/18 words).

A detailed examination of the spatial configuration of each intrusive gesture and its relationship to other gestures in the target word was performed to compare the MAGs with the aphasic subjects normal stop patterns. Each subject will be considered individually.

7.3 FM (Broca's aphasic with AOS)

Only one MAG was noted during the production of word lists and repetition tasks by FM. This was surprising since MAGs had previously been found in the speech of subjects with AOS (Hardcastle and Edwards, 1992; Sugishita et al. 1987), a diagnosis which this subject had. The single example was a velar MAG produced in WI position during the target word "bookshop" 2. The production was phonetically transcribed as [a: bukʃɔp] which indicates that the MAG was not detected through auditory analysis. This was presumably because the MAG was articulated simultaneously with, but released before the WI bilabial plosive. The EPG print-out of the first syllable of the word "bookshop" 2 is given in Figure 7-2. Full velar closure for the MAG can be seen from frames 127 to 132 inclusive (60 msecs). This is much shorter than the WM target velar plosive (280 msecs) and has fewer contacts in the velar region of the palate (rows 6 to 8). The distribution of lingual/palatal contacts for the frames of maximum contact during production of the MAG (frames 128 and 129) are also different to the target WM velar. The MAG has two lateral columns of activated electrodes on both sides of the palate which extend as far as row 1 on the left and row 2 on the right side of the palate and only one row of complete closure (row 8). In contrast, the frames of maximum contact for the target velar (frames 195 to 202 inclusive) do not have as many lateral contacts yet there is full velar closure along two rows (row 7 and 8). Although the MAG has a different spatial arrangement to the target WM velar, the articulation is typical of a velar plosive in WI position for FM.

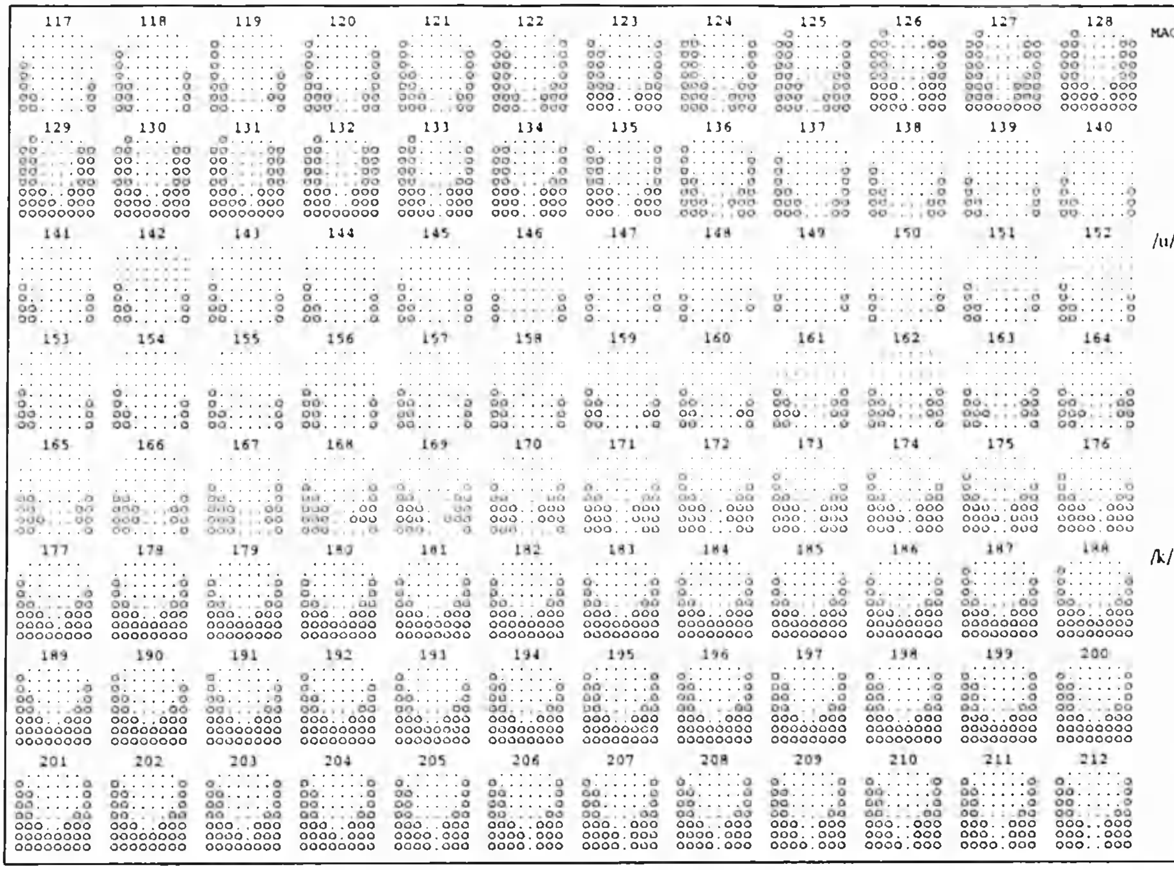


Figure 7-2: EPG print-out of the WI MAG in "bookshop" 2 produced by FM. The word is heard as [a: bukʃɔp].

7.4 MU (Broca's aphasic with AOS)

This subject produced the greatest number of MAGs, forty-one in total on only thirty-one words. The majority of these were alveolar (36/41 = 88%). Fifteen of the thirty-one target words where MAGs were detected contained either an alveolar or a velar plosive target. Velar MAGs occurred exclusively in words where there was a target velar. Duration of the MAGs was variable ranging from 60 msecs to 620 msecs. It was not uncommon for more than one MAG to occur in a target word. When there were multiple MAGs these tended to be all alveolar articulations. The one exception was the target word "bookshop" 1 which contained five alveolar and one velar MAG. The words that contained the MAGs, their auditory based phonetic transcriptions, duration of the MAG and the position of the MAG in the target word are given in Table 7-3. Alveolar and velar MAGs will be considered separately.

Target word	Phonetic transcription	Type of MAG	Duration of MAG (msecs)	Word position
beak 1	[ə ɸ/pi:pt]	alveolar	460	WI
beak 2	[ə pipʰ]	alveolar	300	WI
book 1	[ə put]	alveolar	380	WI
book 2	[ðə put]	alveolar	380	WI
sea 2	[ðə s:i]	alveolar	270	WI
shark 1	[ʌ t:ʃaɹt]	alveolar	620	WI
shark 2	[ðə ts s:aɹt]	alveolar	300 & 270	2 × WI
shop 1	[ðə s:pə s:ɔp]	alveolar	90, 230 & 160*	2 × WI, WF
sun 1	[ðə s sʌn]	alveolar	160	WI
tick 2	[ðə (..) tʰɪkʰ]	alveolar	80	WF
bookshop 1	[ðə ɸuts.tkɹɔt]	alveolar	180, 110, 100, 130, 240	2 × WI, 2 × WM, WF
catkin 1	[ðə t kʰʌtgɪds]	alveolar	420	WI
clock 1	[ʌ t:ɹɔk]	alveolar	150	2 × WI
clock 2	[ʌ kʰɔk]	alveolar	230	WI
hats 1	[ðə s: (..) hats]	alveolar	150	2 × WI
kitkat 1	[kʰ\kʰɪtdat]	alveolar	410	WI
kitkat 2	[ðə (..) kʰɪttat]	alveolar	140	WI
clock (rep 1)	[ðə ( ) kʰɔk]	alveolar	190	WI
clock (rep 2)	[ə (.) tkʰɔk]	alveolar	570	WI
clock (rep 3)	[ðə kʰɔk]	alveolar	140	WI
clock (rep 4)	[ðat tɹɔk]	alveolar	210	WI
clock (rep 5)	[ðə tjɹɔk]	alveolar	60	WI
clock (rep 6)	[ðə xɹɔk]	alveolar	150	WI
kitkat (rep 1)	[tkʰɪtdat]	alveolar	320	WI
kitkat (rep 2)	[ə tkʰɪt˺tat]	alveolar	240	WI
kitkat (rep 5)	[ðə kʰɪttat]	alveolar	180	WI
kitkat (rep 6)	[ə kʰɪt˺katʰ]	alveolar	290	WI
deckchair 1	[dɹɪk.tʲeə]	velar	60	WM
tractor 2	[ðə stɹat˺tɛ]	velar	110	WI
bookshop 1	[ðə ɸuts.tkɹɔt]	velar	230	WM
witchcraft 2	[ðə wɪtsk̠ ɹans]	velar	30	WI
weekday 2	[ðə wi:kde]	alveolar/velar	370	WI

Table 7-3: Target words produced by MU where MAGs were detected on analysis of the EPG data. The corresponding phonetic transcription, type of MAG, duration and position of the MAG are given. The asterisk (*) for duration of the WF alveolar MAG in "shop" indicates that complete alveolar closure was not made. Here duration refers to the time that alveolar contacts which were spatially very different to any other contacts were made (see text below).

7.4.1 Alveolar MAGs

The phonetic transcription reveals that often an articulation other than the target was detected but this was not necessarily transcribed as an alveolar plosive although this was seen from the EPG data ("clock" repetition 6, WI alveolar MAG seen from the EPG print-out → [ðə xɹɔk]; "sun" 1 WI alveolar MAG seen from the EPG print-out → [ðə s sʌn]). Alveolar MAGs tended to be prolonged and involve full contact over rows one to four. This was not untypical of a correct target alveolar plosive for this subject although unusual for the control speakers.

There were several examples of alveolar MAGs during production of a WI bilabial plosive which were also noted in the speech of other aphasic speakers (BA, CR, HL, and IE). All these words had either a target WF velar plosive ("book" and "beak") or a WM velar plosive ("bookshop") where an alveolar plosive was substituted. These substitutions were detected both through auditory analysis and through analysis of the EPG data. Lingual/palatal contacts for the production of "beak" 1 are given in Figure 7-3.

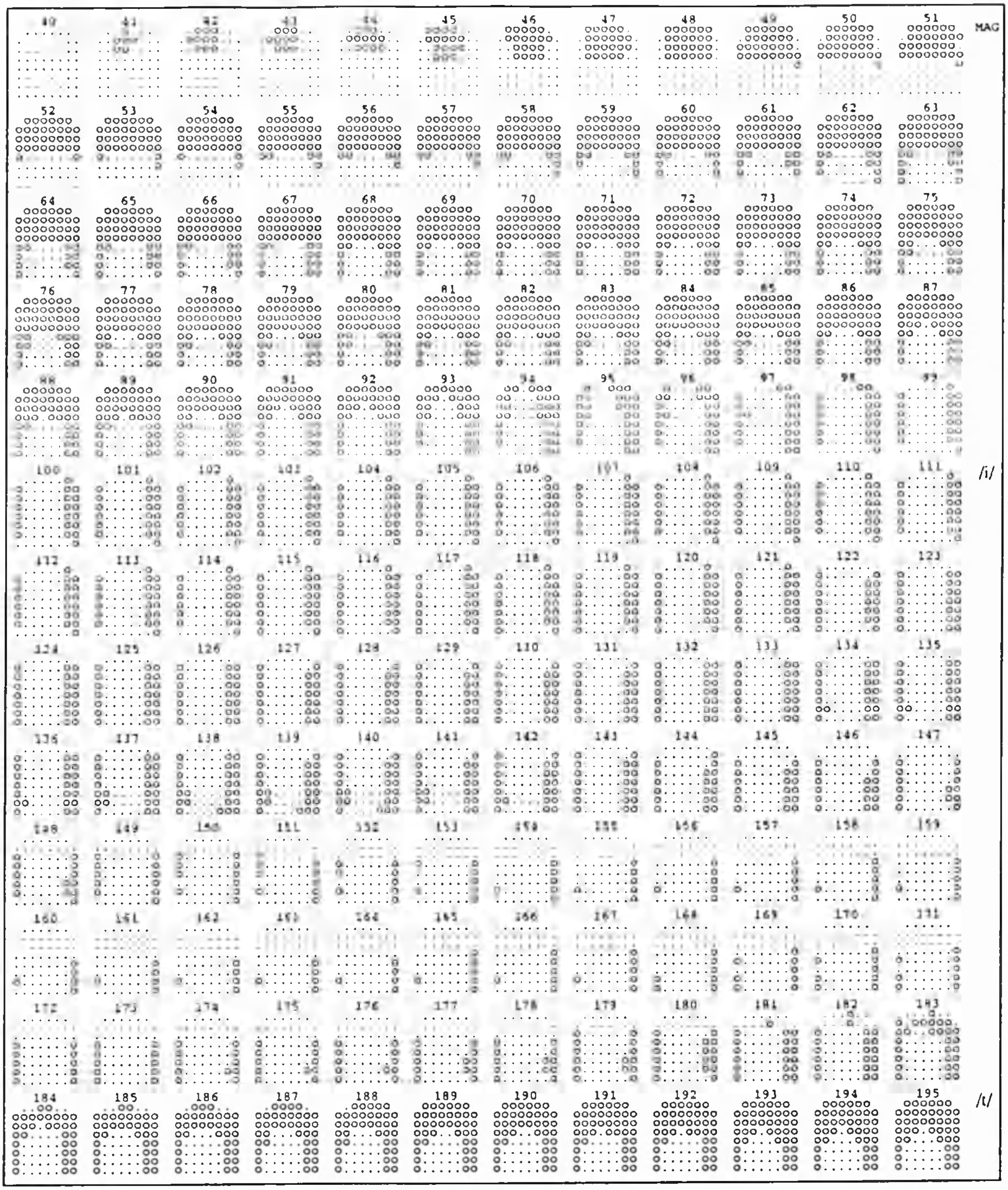


Figure 7-3: EPG print-out of the word "beak" 1 heard as [ə ɸ / pi.pt] produced by MU. An alveolar MAG was only detected in WI position on analysis of the EPG data. The WF velar plosive was heard as an alveolar substitution.

Production of "beak" 1 is different to the other target words where there is a WI bilabial plosive since a misarticulation was detected through auditory analysis. However, this was transcribed as a bilabial fricative ([ɸ]) not an alveolar articulation. Analysis of the EPG data showed that the other target words where a voiceless bilabial fricative ([ɸ]) was detected did not demonstrate similar lingual/palatal contact patterns ("book" 1 and 2, "bookshop" 1 and 2). The onset of the MAG in Figure 7-3 is unusual. It commences at frame 41 where contacts are made apically and in the centre of the palate. The lateral contacts follow after full closure has been established. The approach to the alveolar substitution in WF position is more typical with the lateral contacts being made first and this activation spreading up the left and right sides of the palate to the alveolar region. The atypical apical onset was also seen during production of the MAG in "book" 1 but not "beak" 2, "book" 2 or "bookshop" 1. The alveolar MAG in Figure 7-3 has more contacts than would be expected for a normal speaker. However, the gesture is typical of MU's speech and was seen for all alveolar MAGs where the target was a bilabial plosive [b].

MU produced alveolar MAGs during eight of the twelve repetitions of "clock". Table 7-3 indicates that these each had a different phonetic transcription. An alveolar and velar was detected for only one production of "clock" (repetition 2) through auditory analysis. Inspection of the EPG data revealed differences in the lingual/palatal contact patterns for these alveolar MAGs despite all being produced in WI position during production of the same word. Differences involved the sequencing of the alveolar MAG and the target velar both of which were produced during these eight repetitions. For five of the repetitions ("clock" 2, "clock" repetitions 1, 3, 4, and 5) the alveolar MAG preceded and was fully released prior to the WI velar plosive. Despite the similarities in their EPG print-outs these were perceived auditorily very differently. For "clock" 2 and "clock" repetition 3 a normal production of the target word was heard. For "clock" repetition 4 a partially voiced /t/ was detected and for "clock" repetition 5 the /kl/ cluster became [t͡ʃɹ]. Although spatially similar, temporally these five productions were different. The duration of the alveolar MAG ranged from 60 msecs to 230 msecs.

The lingual/palatal contacts for "clock" repetitions 2 and 6 were similar. The alveolar MAG precedes the velar gesture in both repetitions. However, unlike "clock" 2, and "clock" repetitions 1, 3, 4, and 5, full velar closure was made before the MAG was released during repetition 6 which resulted in a period of double alveolar/velar articulation. In repetition 2 there is a period of overlap between the alveolar and the velar although complete double articulation is not evident. Whilst the sequencing of the alveolar and velar articulations was similar the contacts and the duration of these differed. In "clock" repetition 6 the alveolar articulation was retracted and the velar closure uses more lingual/palatal contacts than is typical for this subject. In "clock" repetition 2 the alveolar MAG and the velar plosive are spatially more typical for MU. The duration of the MAGs in these two productions is also very different. In "clock" repetition 6 full closure for the alveolar MAG is held for 150 msecs, for repetition 2 it is 570 msecs. The sequencing of the alveolar and velar articulations for these two productions is shown in Figure 7-4 ("clock" repetition 6) and Figure 7-5 ("clock" repetition 2).

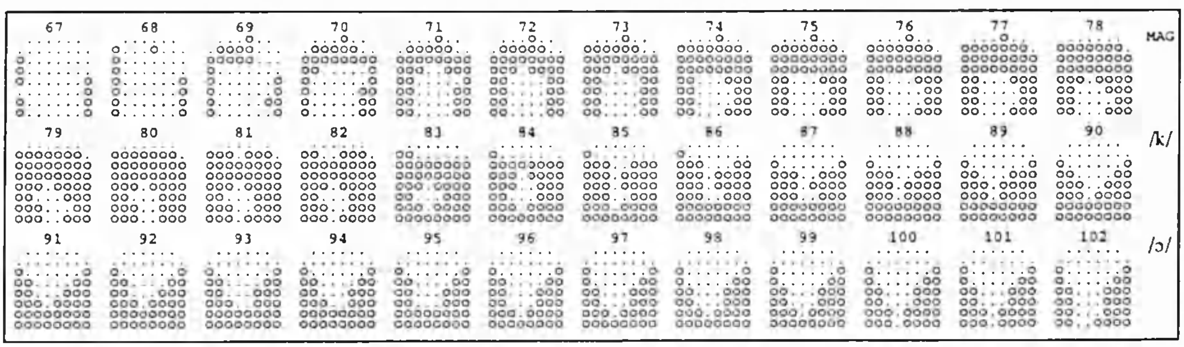


Figure 7-4: EPG print-out of the WI alveolar MAG and velar target in "clock" (repetition 6) produced by MU. Phonetic transcription for this production was [ðə xɹɔk].

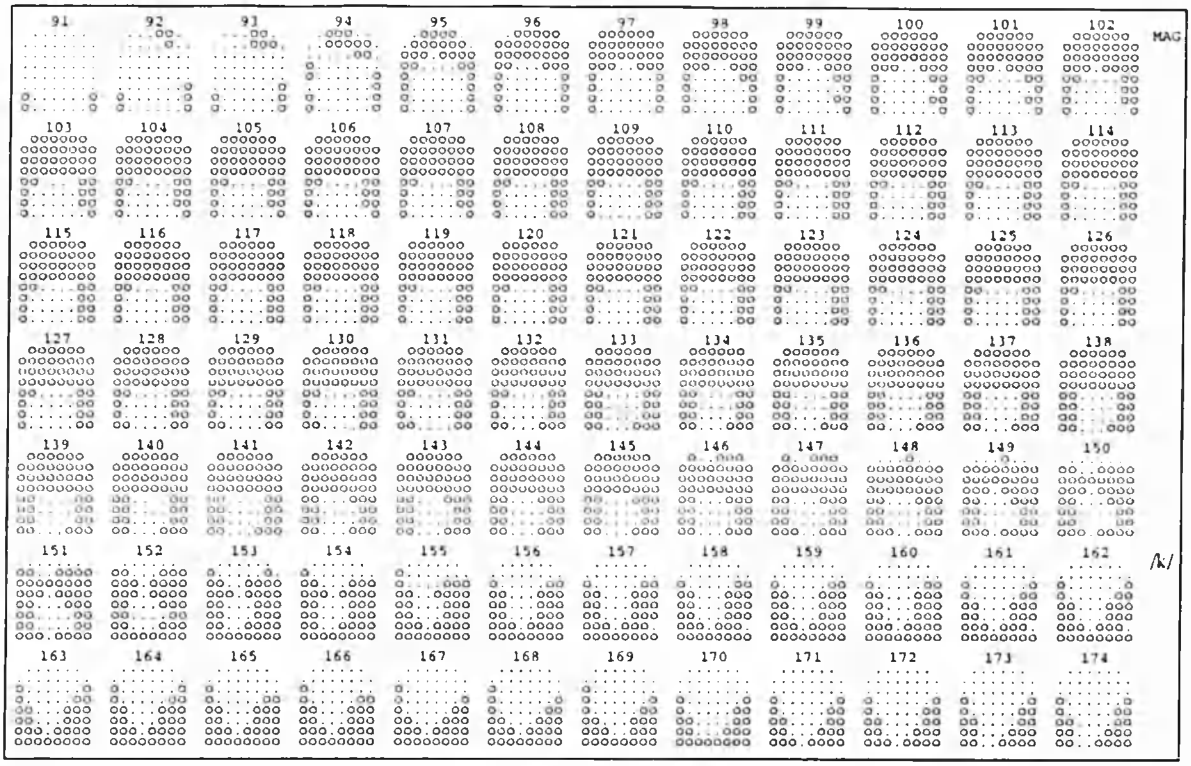


Figure 7-5: EPG print-out of the WI alveolar MAG and velar target in "clock" (repetition 2) produced by MU. Phonetic transcription for this production was [ɔ (.) t͡kʰɔk].

Figure 7-4 shows a period of double articulation (frames 83 and 84) in WI position. In Figure 7-5 the frame of release for the alveolar MAG is the same as the frame of closure for the velar plosive (frame 152). The approach to the velar is clearly evident during alveolar closure.

"Clock" 1 differed from the other repetitions because the MAG was repeated. The sequence is shown in Figure 7-6.

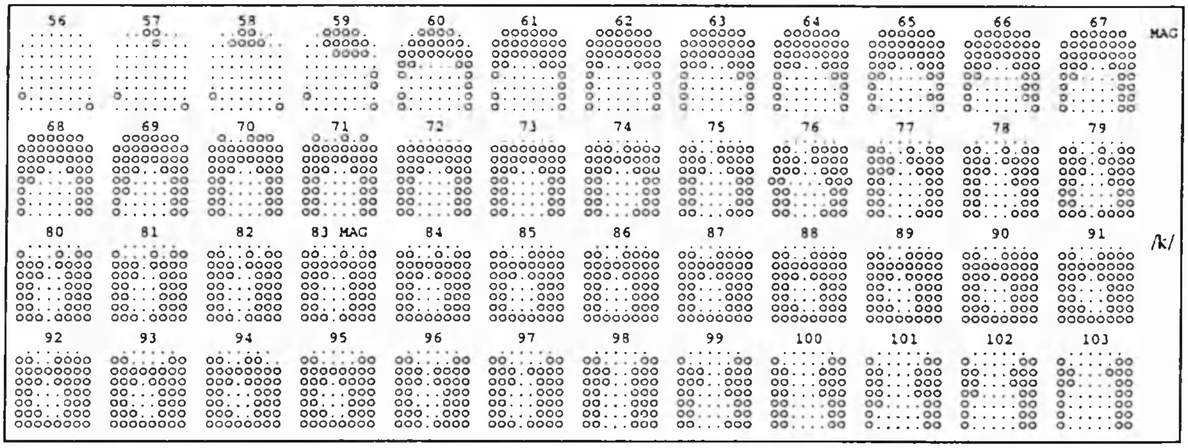


Figure 7-6: EPG print-out of the MAGs in WI position for the word "clock" 1 produced by MU. The word was heard as [ʌ tːɹɔk].

The approach to the first MAG is unusual because it starts with apical contacts which then spread to include the lateral margins. This closure is released at frame 75 although contacts in the alveolar and palatal regions of the palate are held in what appears to be a fricative articulation. Full alveolar closure is made again at frame 83 and velar closure at frame 84. Both are released at frame 96 with the /t/ being detected auditorily. The second alveolar MAG is unlike a correct target alveolar production for this subject since it is retracted in its' placement. However, this is similar to the MAG in "clock" repetition 6.

Alveolar MAGs occurring in words with target WI alveolar or post alveolar fricatives were all released directly into the alveolar fricative articulation. For "sun" 1 a brief alveolar fricative (20 msecs) was seen prior to full closure. Since the target fricatives immediately followed the MAGs it is proposed that these alveolar MAGs may be more accurately described as an overshoot of the target fricative. They varied considerably in their duration (90 to 620 msecs).

In "shark" 2 and "shop" 1 these MAGs or overshoots were repeated. In the former the first MAG is released into an alveolar fricative which is held for 60 msecs following which full closure is made. However, in "shop" 1 following the first MAG and fricative, full release can be seen on the EPG trace before MU makes full closure for the second time. This appears to be a second attempt at the WI target whereas in "shark" 2 the whole sequence appears to be a single attempt at the fricative. A third alveolar MAG is made in WF position of "shop" 1 although this is undetected through auditory analysis. The MAG is spatially different to the WI in both approach and maximum contact. The WF MAG is shown in Figure 7-7 below.

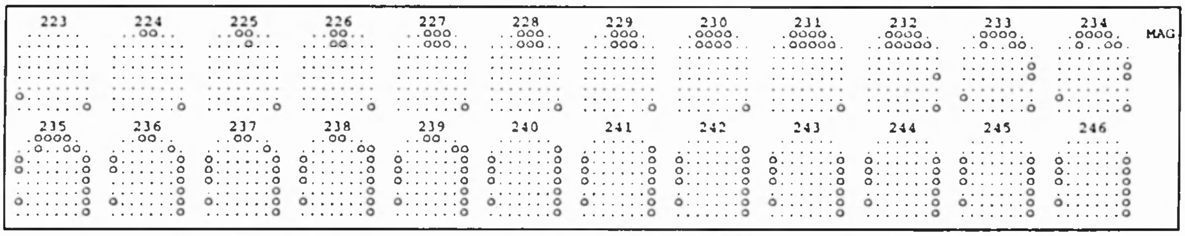


Figure 7-7: EPG print-out of the WF alveolar MAG in "shop" 1 produced by MU. The word was heard as /ðə s:pə s:ɔp/.

This WF MAG is not detected through auditory analysis. Instead the target bilabial /p/ is heard. The lingual/palatal contacts in Figure 7-7 are not typical of an alveolar articulation and full closure is not made.

Six of the twelve productions of "kitkat" contained alveolar MAGs, all of them in WI position. An alveolar articulation was only detected once during production of "kitkat" repetition 2, phonetically transcribed as [ə tk^{h}ɪt̚tat]. Five of the MAGs (all except repetition 6) were fully released prior to the onset of the velar plosive. The period between the release of the MAG and full closure for the velar ranged between 20 and 70 msecs. Two of these alveolar MAGs showed apical onsets (similar to Figure 7-3). Full alveolar closure followed lateral contacts for the other three productions. The target WI velar following the MAG was spatially normal for all productions. "Kitkat" repetition 6 was different to other productions since the MAG was not released until after full velar closure had been made. This resulted in a brief period of double alveolar/velar articulation (20 msecs). Furthermore in WM position a single velar articulation was noted. In all other productions of "kitkat" where an alveolar MAG was noted in WI position, a single alveolar or the correct alveolar/velar sequence was seen through analysis of the EPG data in WM position. For "kitkat" repetition 6 it appears that the WI and WM consonants have exchanged places which suggests a problem with the sequencing of the phonemes. In WI position an alveolar/velar sequence is made and in WM position a single velar plosive was articulated.

The lingual/palatal contacts made during production of "catkin" 1 were similar to those made during productions of "kitkat" (except repetition 6) where a MAG was detected. The alveolar MAG was spatially normal and released 50 msecs prior to full velar closure. The target /tk/ articulation in WM position was also correctly sequenced and included a period of double alveolar/velar articulation. However, an increased number of electrodes than would be considered normal were observed.

There was a single example of an alveolar MAG in WF position where the target gesture was a velar plosive. This was seen during production of the word "tick" where an alveolar MAG was also seen in WI position. This WF MAG differed to those in WI position because full alveolar closure was not made until after velar closure and it was released prior to the release of the WF /k/. The lingual/palatal contacts for this sequence are shown in Figure 7-8.

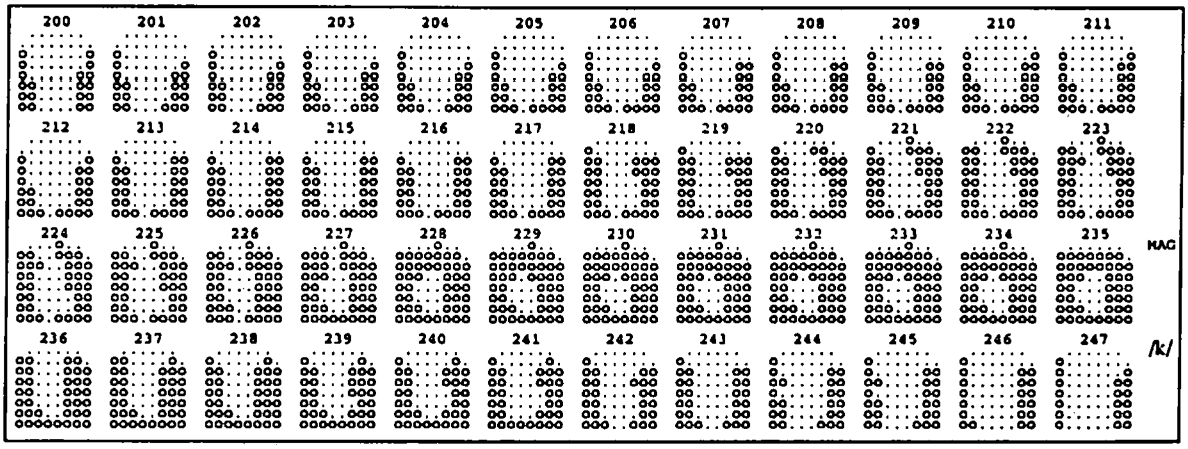


Figure 7-8: EPG print-out of the WF alveolar MAG and target velar in the word "tick" produced by MU. The word was heard as [ðə (..) tʰɪkʰ]

Full alveolar closure for the WF MAG commenced at frame 228. Velar closure preceded at frame 227. This differs from the WI alveolar MAGs where the MAG is articulated prior to the target velar. In WF position the MAG only occurs during full closure for the target velar and is released 70 msecs before the target.

7.4.2 Velar MAGs

Velar MAGs occurred on disyllabic target words. Two were observed in WI and two in WM position. During production of "witchcraft" 2 the velar MAG occurred simultaneously with the WI labial-velar approximant /w/. The MAG appeared to be a spatially normal velar plosive which was undetected through auditory analysis. The MAG in "tractor" 2 occurred simultaneously with the alveolar articulation. A voiceless alveolar fricative was detected auditorily in WI position and this could be seen on the EPG print-out (Figure 7-9). The following alveolar plosive was retracted and had the appearance of a fricative articulation. Full alveolar closure was only made over two frames (frames 138 and 139). However there was constriction along rows 2 and 3 such that only a single electrode was preventing full closure from frames 132 to 148 inclusive. The lingual/palatal contact patterns are shown in Figure 7-9 below. In WM position the EPG print-out indicated that the target velar plosive was omitted leaving a single alveolar plosive which was normal in its spatial configuration.

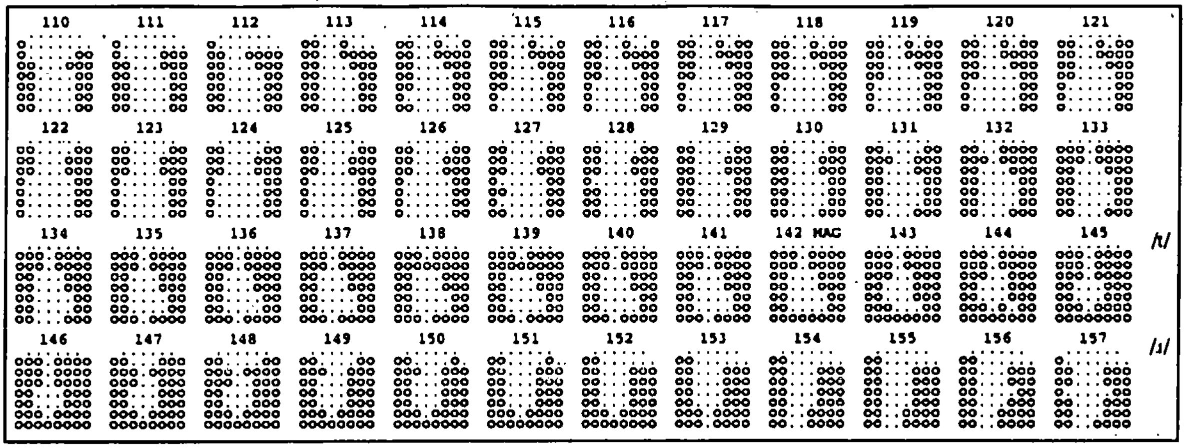


Figure 7-9: EPG print-out of the WI velar MAG in "tractor" 2 produced by MU, phonetically transcribed as [ðə stɹatˀtɛ].

Productions of "bookshop" 1 and "deckchair" 1 were similar in that MU correctly articulated the target WM velar both spatially and temporally but then repeated the velar articulation during production of the following consonant or after it. For "bookshop" 1 the target velar was articulated and released into a post alveolar fricative. After the release of the fricative MU made a further velar articulation. In "deckchair" 1, following release of the target WM velar, MU produced the stop portion of the affricate which appeared prolonged. During this closure phase velar contacts were added such that there was a brief period of double alveolar/velar articulation. The velar articulation was released first leaving an alveolar closure which was eventually released into the fricative portion of the affricate. This velar MAG could alternatively be interpreted as an increase in closure for the voiceless affricate /tʃ/. The lingual/palatal contacts for the WM /ktʃ/ sequence including the velar MAG can be seen in Figure 7-10.

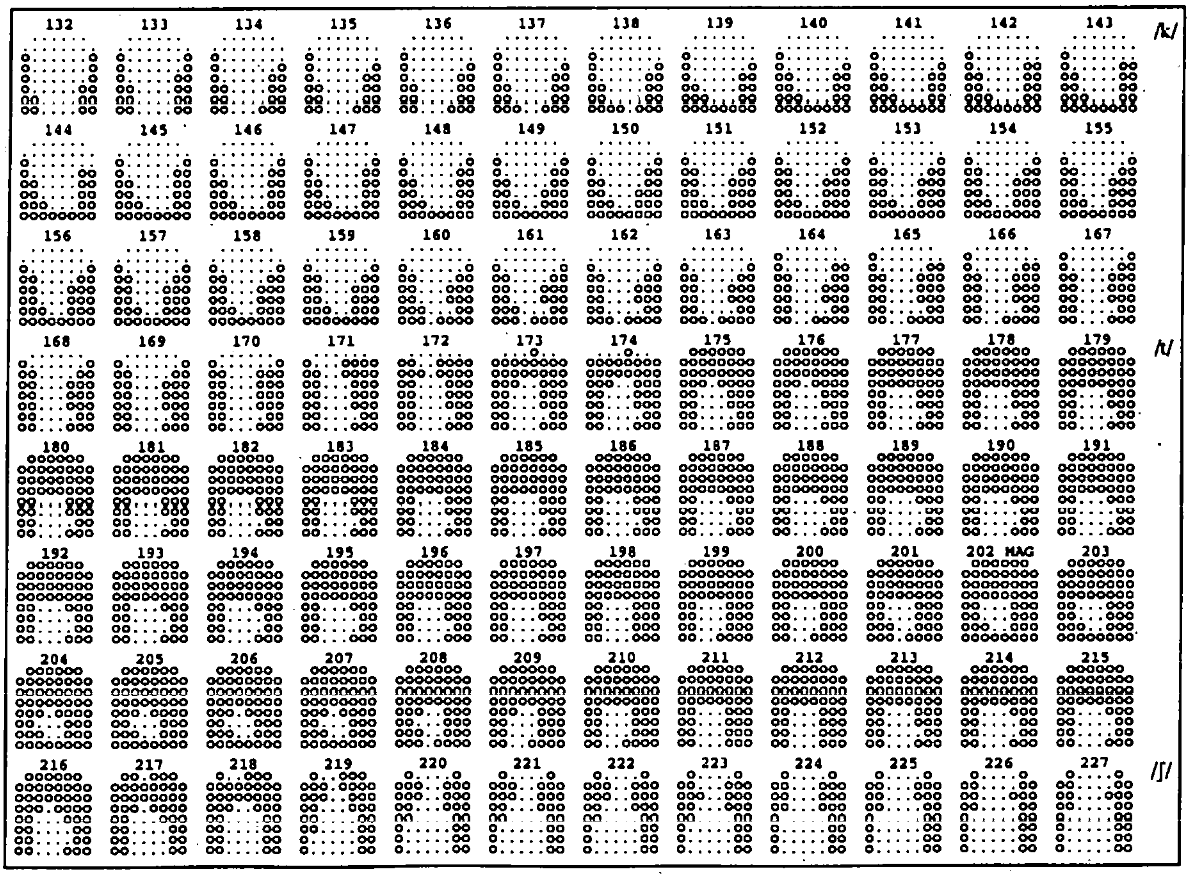


Figure 7-10: EPG print-out of the WM /ktʃ/ sequence in "deckchair" with velar MAG produced by MU. The word was heard as [dɹɪk.tʲɛə]

In Figure 7-10 MU makes full velar closure for the target WM consonant in frame 139 which is held until frame 159. Alveolar closure for the WM affricate commences at frame 173. The closure period is excessively long, lasting 460 msecs. During this closure an increase in velar contacts can be seen and full velar closure is made at frame 202 until frame 207. This is undetected through auditory analysis. The velar MAG is released several frames before the alveolar portion of the affricate.

7.4.3 Double velar/alveolar MAG

There was one example of a double velar/alveolar MAG during production of the word lists and repetition tasks. This occurred in WI position during production of the word "weekday" 2 which has a target velar/alveolar sequence word medially. The alveolar contacts are more palatal in appearance since they are concentrated along rows 3 and 4. The MAG is made during production of the labial-velar approximant and is not detected through auditory analysis. Whilst velar closure is made first there is a noticeable increase in alveolar contacts prior to this. The MAG appears very gross with a large number of electrodes being activated. This is also seen in WM position for the target velar/alveolar sequence which was phonetically transcribed as a normal production. The velar/alveolar MAG EPG sequence is shown in Figure 7-11.

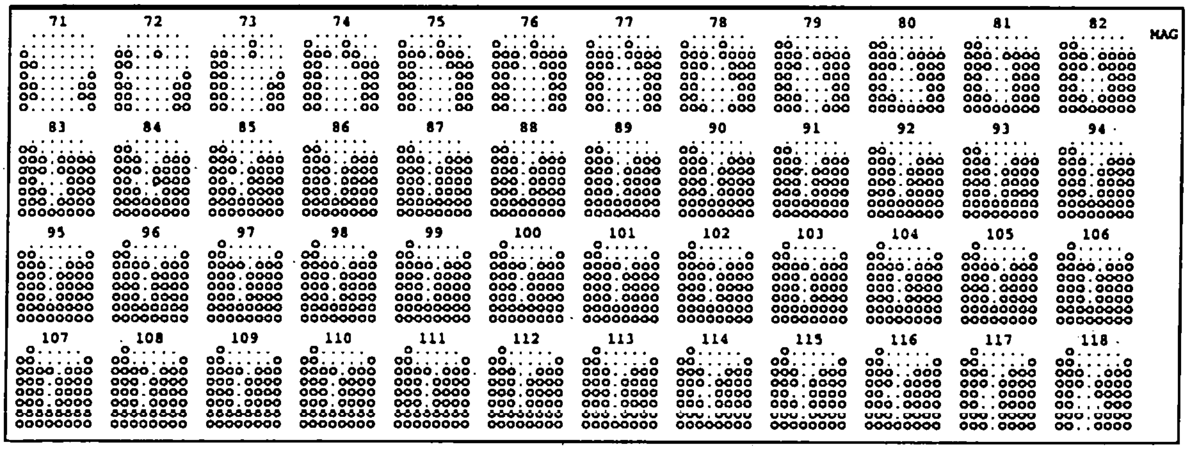


Figure 7-11: EPG print-out of the velar/alveolar MAG in WI position during production of the word "weekday" 2 by MU. The word was heard as [ðə wi:kde].

Contacts in row 3 commence at frame 72 before full velar closure in frame 80. Complete closure in the anterior portion of the palate is not over a single row but a combination of rows. This sequence is very similar in appearance to the WM target despite the large number of activated electrodes.

7.4.4 Summary

MU produced more MAGs than any other aphasic, forty-one in total. The majority of these MAGs were alveolar in appearance. These alveolar MAGs typically had a large number of activated electrodes which is considered abnormal. However, this was a feature of MU's articulation and not of the MAGs. There were two distinct onsets to the alveolar MAGs. The more usual approach that would be seen in normal speakers involves the activation of the lateral contacts prior to closure in the alveolar and/or palatal region. MU also produced alveolar plosive articulations which were the reverse of this sequence, that is central apical contacts preceded the addition of the lateral seals. This appeared to be a feature of this aphasic speaker and is not considered to be normal sequencing of lingual/palatal contacts for an alveolar plosive. Velar MAGs only occurred in words where there was a target velar plosive. More alveolar MAGs occurred in words where there was a target velar plosive than not (30/36).

Where the word to be produced started with a velar MU frequently made an alveolar MAG prior to the velar articulation. This was usually released before the velar target was realized but occasionally a double alveolar/velar gesture occurred. Alveolar MAGs were also frequently seen during production of a WI bilabial plosive although undetected through auditory analysis.

7.5 BA (Broca's aphasic without AOS)

Three MAGs were identified in the speech of BA. Two were alveolar articulations and one was a velar. All the MAGs occurred in WI position. Two of the target words contained the MAG. The alveolar MAGs occurred during production of the words "fish" 2 and "cocktail" 1, the velar MAG was noted at the beginning of the word "beak" following production of the indefinite article. The words during which BA produced an MAG, the position of the MAG, the phonetic transcription of the word and the duration of the MAG are given in Table 7-4.

Alveolar MAGs				Velar MAGs			
Target	Phonetic transcription	Duration of MAG (msecs)	Word position	Target	Phonetic transcription	Duration of MAG (msecs)	Word position
fish 2	[ə fɪʃ]	250	WI	beak 2	[ə ʁ bik]	60	WI
cocktail 1	[tʰɔt̚teɪl]	80	WI				

Table 7-4: Target words produced by BA where an alveolar or velar MAG was detected through analysis of the EPG data. The corresponding phonetic transcriptions, duration of the closure period and position of the MAG are given.

The alveolar MAG in "fish" was more apical in appearance (see Figure 7-12) than the MAG in "cocktail" (see Figure 7-13). In the first example, lateral contacts were made after closure in the first row had been established and even then there was lateral escape of air on the right side (see Figure 7-12, frames 118 to 137). Release of the closure was asymmetrical spreading from the right side of the palate. This pattern of approach and release was typical of BA and were also seen during productions which showed correct EPG patterns and phonetic transcriptions. The MAG occurred prior to the frication for the labiodental fricative and was fully released 1510 msecs before the target articulation commenced.

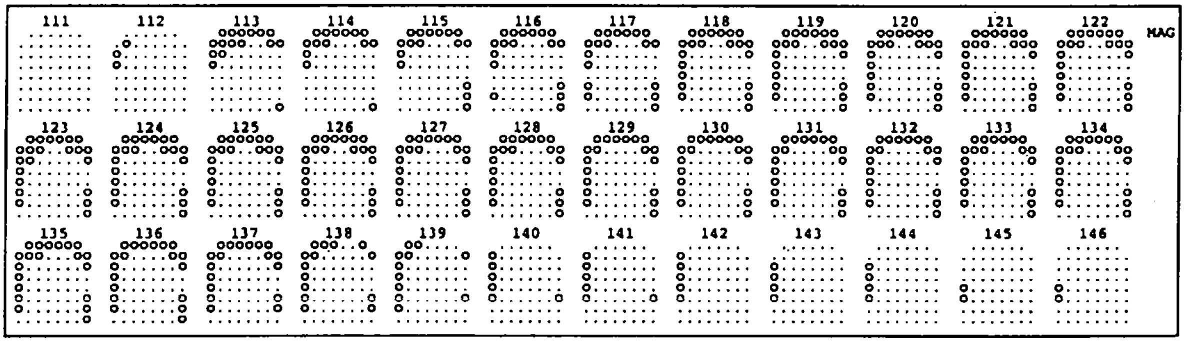


Figure 7-12: EPG print-out of the WI alveolar MAG in "fish" 2 produced by BA, phonetically transcribed through auditory analysis as [ə fɪʃ]. The MAG occurred before the start of friction.

For "cocktail" the alveolar MAG occurred following the WI velar target. More lingual/palatal contacts were made in this example and the lateral seals were complete (see Figure 7-13).

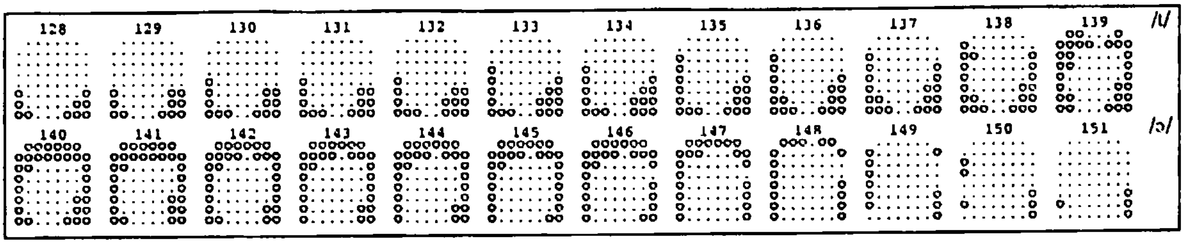


Figure 7-13: EPG print-out of the WI alveolar MAG in "cocktail" 1 produced by BA. The word is heard as /tʰɔtʼtel/.

The MAG in "cocktail" 1 was similar in appearance to the WM target /t/ as least as far as the alveolar contact zone is concerned. The approach to closure and the frame of maximum contact for both the MAG and the target gesture can be seen in Figure 7-14. Both make contacts along row 2 which then spread forward to include row 1. The frame of maximum contact for the WM production reveals incomplete closure on the right side and fewer velar contacts than the MAG. The velar contacts for the MAG are possibly part of the release of the WI velar target which was articulated but undetected through auditory analysis. Instead a voiced alveolar plosive was heard in WI position.

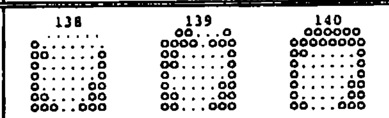
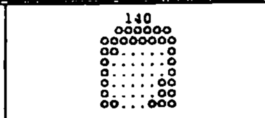
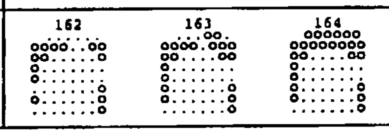
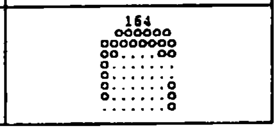
Target word "cocktail" 1	Approach to alveolar closure	Frame of maximum contact
Word Initial alveolar MAG		
Word Medial alveolar target		

Figure 7-14: Approach to closure and frame of maximum contact for the WI alveolar MAG and the WM target /t/ in "cocktail" 1 produced by BA. The word was heard as /tʰɔtʼtel/.

The duration of the two MAGs reported so far are very different. The MAG in "fish" 2 was maintained for 250 mscs but only 70 mscs for "cocktail".

The velar MAG occurred during production of the word "beak" 2. Whilst full closure was not made in the velar region the pattern was considered spatially normal for a velar plosive produced by BA (see Figure 7-15). It followed the indefinite article and was released 320 mscs before the onset of the vowel in "beak" 2. It would seem therefore that it was articulated at the same time as the bilabial plosive resulting in a double velar/bilabial articulation. A voiced uvular fricative ([ʁ]) was detected through auditory analysis.

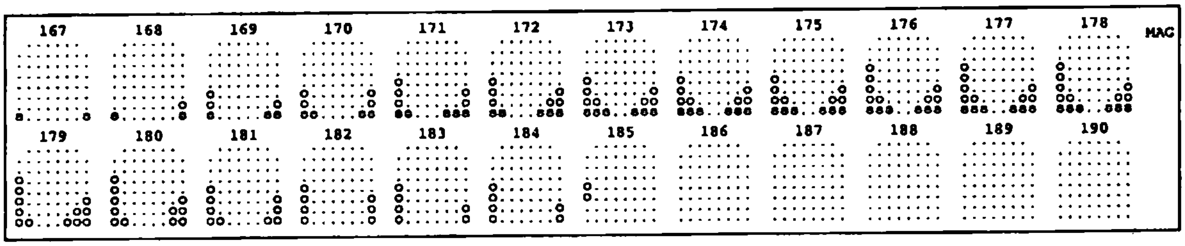


Figure 7-15: EPG print-out of the WI velar MAG in "beak" 2 produced by BA. The word is heard as [ə ʁ bikʼ].

The WF velar plosive in "beak" 2 was both spatially and temporally different to the WI MAG (see Figure 7-16). In WF position BA produced full velar closure for 100 mscs. The increase in lateral contacts is probably due to the preceding [i].

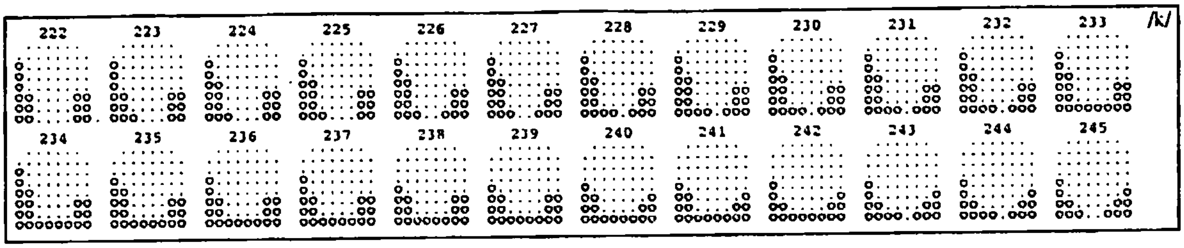


Figure 7-16: EPG print-out of the WF velar target in "beak" 2 produced by BA. The word is heard as /ə ʁ bik/.

The duration of the velar MAG is difficult to determine since full closure was not made and there is no indication of release or closure on the acoustic trace. However, the duration of maximum contact in row 8 was 50 msecs (frames 173 to 178 inclusive) and is likely to correspond to the closure if indeed full closure was made. The velar MAG pattern in "beak" 2 is similar in appearance to some WI target velar articulations. An example of a normal target velar plosive where full closure was not seen on analysis of the EPG data can be seen in Figure 7-17.

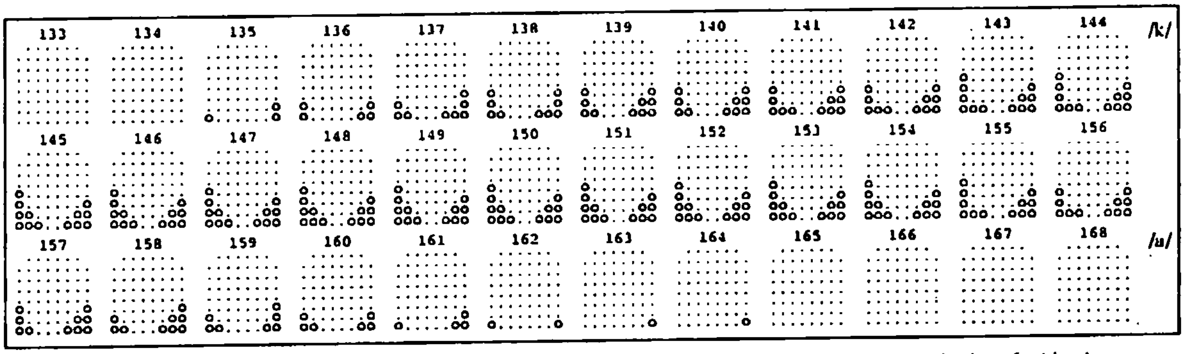


Figure 7-17: EPG print-out of the WI velar in "car" 2 produced by BA. This word was transcribed as /ə kʰaɹ/.

The EPG patterns in Figure 7-17 are spatially similar to the velar MAG in Figure 7-15. Neither example shows full closure in the velar region and contact spreads further up the left side of the palate when compared to the right. However, the correct production in Figure 7-17 is longer in duration than the MAG in Figure 7-15. Maximum contact in row 8 is held for 160 msecs (frames 141 to 156 inclusive) in the former compared to only 50 msecs for the MAG. This may indicate that BA selected the phoneme /k/ and started to articulate but then aborted the incorrect articulation before it was detected auditorily.

BA produced three MAGs during production of the word lists and the repetition task. These gestures, as we have seen, are spatially normal productions. The MAGs occurred both in words where there was an identical target phoneme and words where there was not.

7.6 CR (Broca's aphasic without AOS)

Nine MAGs were noted in the speech of CR, five were alveolar and four were velar. All MAGs bar one were produced in WI position either prior to the target WI phoneme or simultaneously with it. The words for which CR produced an MAG, the position of the MAG, the phonetic transcription of the word and the duration of the MAG are given in Table 7-5 below.

Alveolar MAGs				Velar MAGs			
Target	Phonetic transcription	Duration of MAG (msecs)	Word position	Target	Phonetic transcription	Duration of MAG (msecs)	Word position
beak* 1	[ʌ bik]	30	WI	tear 2	[tʲiɹ]	30	WI
dark 1	[ʌ daɹk]	40	WF	brush 2	[ʌ bɹʌʃ]	130	WI
key* 2	[ʌ fgi]	180	WI	racer 2	[ʌ šɹesɜɹ]	90	WI
mouse* 1	[ʌ maus]	50	WI	weekday 2	[ʌ bik˺be]	80	WI
witchcraft 2	[swɪʃk̟aft]	90	WI				

Table 7-5: Target words produced by CR where alveolar and velar MAGs were detected through analysis of the EPG data. The corresponding phonetic transcriptions, duration of the closure period and position of the MAG are given. Those words marked with an asterisk (*) indicate that full alveolar closure was not produced.

Alveolar and velar MAGs will be considered separately.

7.6.1 Alveolar MAGs

None of the alveolar MAGs were detected through auditory analysis. For "key" 2 and "witchcraft" 2 an intrusive gesture was identified on analysis of the EPG data but the auditory impression did not support the lingual/palatal contact patterns. For "key" 2 a labiodental fricative [f] was heard prior to a voiced velar plosive. The EPG patterns for this sequence are given in Figure 7-18 below.

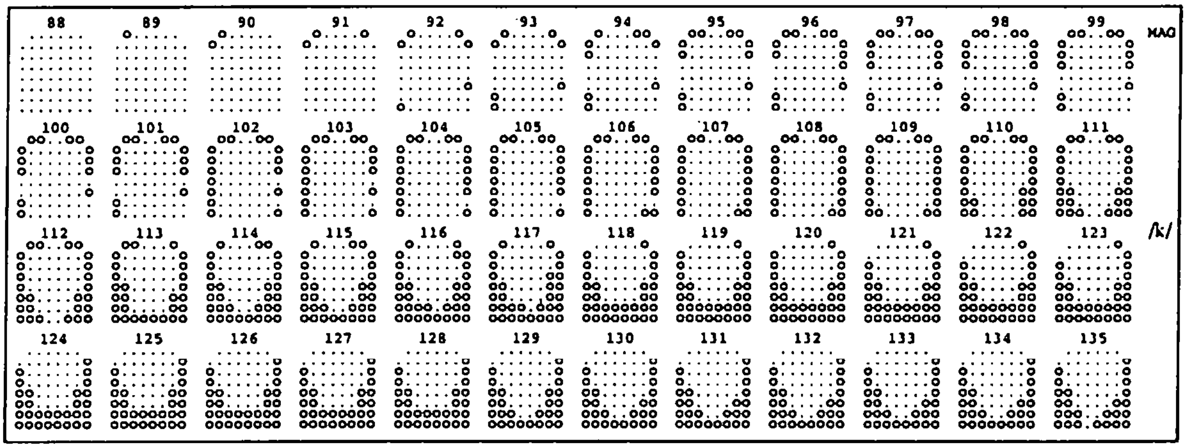


Figure 7-18: EPG print-out of the WI MAG and target velar plosive for the word "key" 2 produced by CR. The word is heard as [ʌ fgi].

The lingual/palatal contact patterns in Figure 7-18 indicate the presence of a MAG prior to the velar closure in WI position. However, since there is constriction in the alveolar region of the palate and contact along the lateral margins of the palate the expected auditory impression would be of an alveolar fricative and not a labiodental fricative as was heard and transcribed ([ʌ fgi]). However target alveolar fricatives produced by CR usually have a greater number of contacts which result in a more constricted configuration. Therefore this is not a typical alveolar fricative pattern for this aphasic speaker. Instead the EPG contact patterns between frames 95 and 106 are more typical of the approach phase to an alveolar plosive produced by CR. The approach to alveolar closure for the word "tip" 1 is given in Figure 7-19 for comparison.

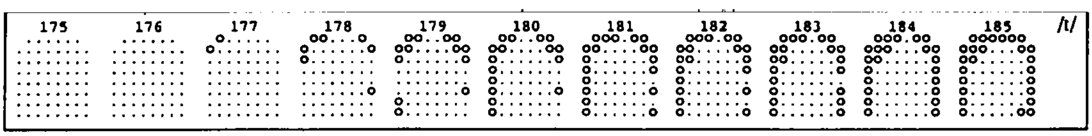


Figure 7-19: EPG patterns of the approach to alveolar closure for the word "tip" 1 produced by CR heard as [ʌ tʰɪp].

The MAG in Figure 7-18 (frames 89-109) is very similar in appearance to the patterns in Figure 7-19 (frames 176-181). Therefore this MAG is similar to the approach phase of an alveolar plosive produced by CR although longer in duration.

Production of the target word "witchcraft" 2 was transcribed phonetically as [swɪʃk̟aft]. Whilst an alveolar fricative could be seen on analysis of the EPG data this then progressed into an alveolar plosive which was not detected through auditory analysis. This WI MAG(s) can be seen in Figure 7-20.

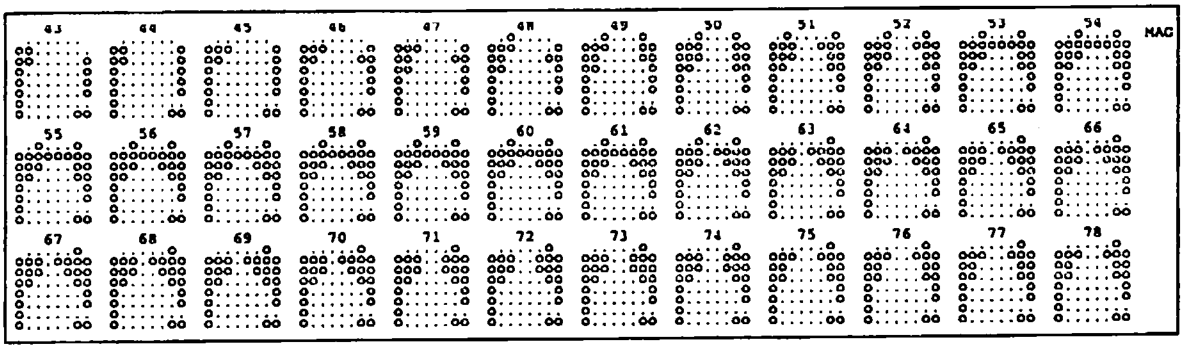
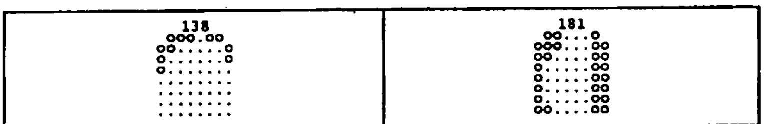


Figure 7-20: EPG print-out of the WI MAG(s) prior to the WI [w] in "witchcraft" 2 produced by CR. The word was heard as [swɪʃk̟aft].

An alveolar constriction can be seen up to frame 52 which then becomes full alveolar contact between frames 53 and 61 inclusive. This is released into another alveolar fricative which is likely to be the reason why a fricative and not a plosive is detected through auditory analysis. Both the alveolar fricative and the plosive are a little retracted. The latter part of this misdirected sequence (frame 53 onwards) is similar to what would be expected for the WM affricate /tʃ/ which CR replaces with a post alveolar fricative (/ʃ/).

The MAG in "mouse" 1 is similar in appearance to the MAG in "key" except that there are no lateral EPG contacts. The patterns are suggestive of either a fricative articulation or the approach phase to an alveolar plosive since there is no complete closure. In comparison to the target alveolar fricative in WF position there are less contacts produced during the MAG with the lateral contacts only reaching back as far as row 4 on the left side of the palate and row 3 on the right. The target phoneme in WF position uses lateral contacts throughout the whole of the palate. The frames of maximum contact for the MAG and the target are given in Figure 7-21.



WI Alveolar MAG	Target WF alveolar fricative

Figure 7-21: Frame of maximum contact in the alveolar and palatal regions for the MAG and target /s/ in "mouse" 1 produced by CR.

The target alveolar fricative has many more contacts and less constriction across row 1 than the MAG which was undetected through auditory analysis.

From analysis of the EPG data it appears that none of the alveolar MAGs produced by CR are typical of alveolar targets correctly produced elsewhere in the speech data.

7.6.2 Velar MAGs

All the velar MAGs produced by CR were in word initial position. For "tear" 2, "racer" 2 and "weekday" 2 the phonetic transcriptions reveal that a sound other than the target was detected. However, the EPG data identified velar contacts which were not heard. The EPG print-out of the word "racer" 2 is given in Figure 7-22. This word was transcribed as [ʌ s̆ɹesɜɹ] indicating that a short alveolar fricative had been heard prior to the /ɹ/. However, on analysis of the EPG data a clear velar closure is evident commencing at frame 84 and is released 90 msecs later at frame 93. The lateral contacts and constriction following this (frame 93 to 109) which are similar in appearance to the WM /s/ is probably responsible for the detection of an alveolar fricative in WI position. However, on analysis of the waveform there was no evidence of friction (Figure 7-23). The velar contacts produced by CR are considered spatially normal for a velar plosive produced by this speaker elsewhere yet they were undetected through auditory analysis.

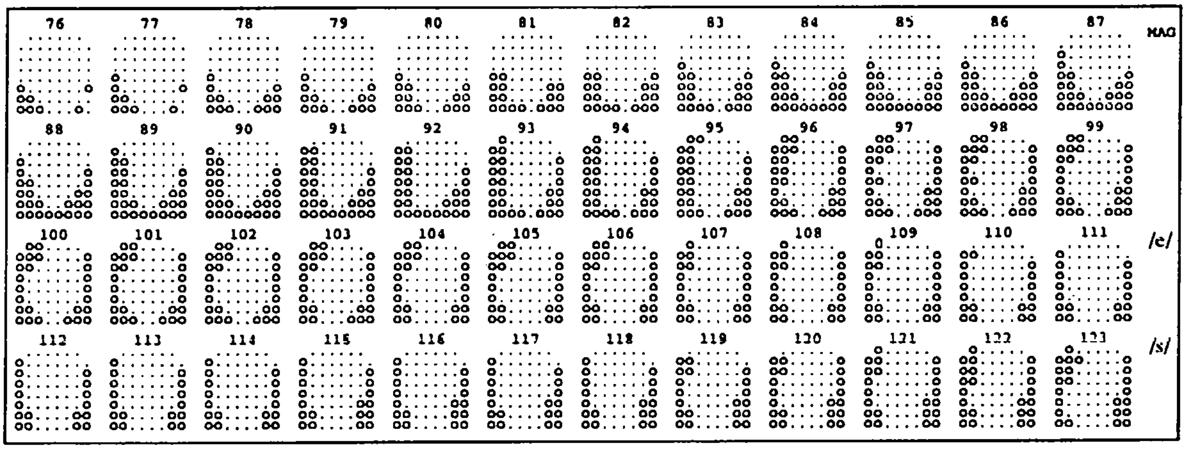


Figure 7-22: EPG print-out of the WI velar MAG in "racer" 2 produced by CR. The word is heard as [ʌ s̆ɹesɜɹ].

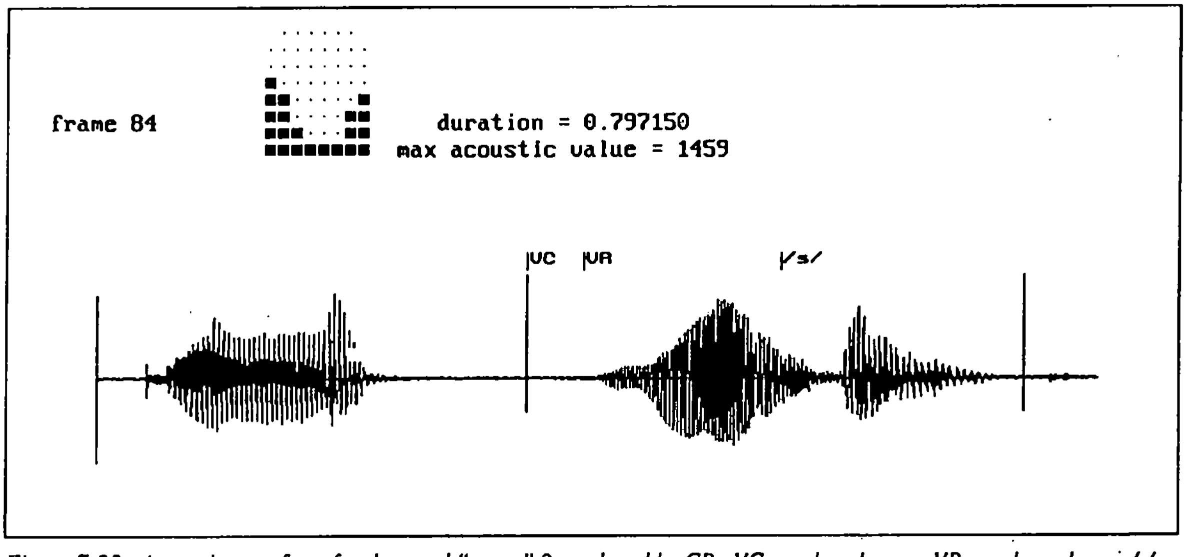


Figure 7-23: Acoustic waveform for the word "racer" 2 produced by CR. VC = velar closure; VR = velar release; /s/ = start of target alveolar fricative. No frication was evident on analysis of the waveform following the release of the velar MAG (VR) prior to regular glottal pulsing for the vowel. The word was phonetically transcribed as [ʌ s̆ɹesɜɹ].

In contrast, "brush" 2 was heard as a normal error free production. However, analysis of the EPG data revealed a clear velar closure lasting 130 msecs which was spatially normal and therefore similar in appearance to the velar MAG in "racer" 2. Inspection of the acoustic waveform indicated that this MAG occurred simultaneously with the bilabial closure but was released prior to the bilabial plosive (see Figure 7-24).

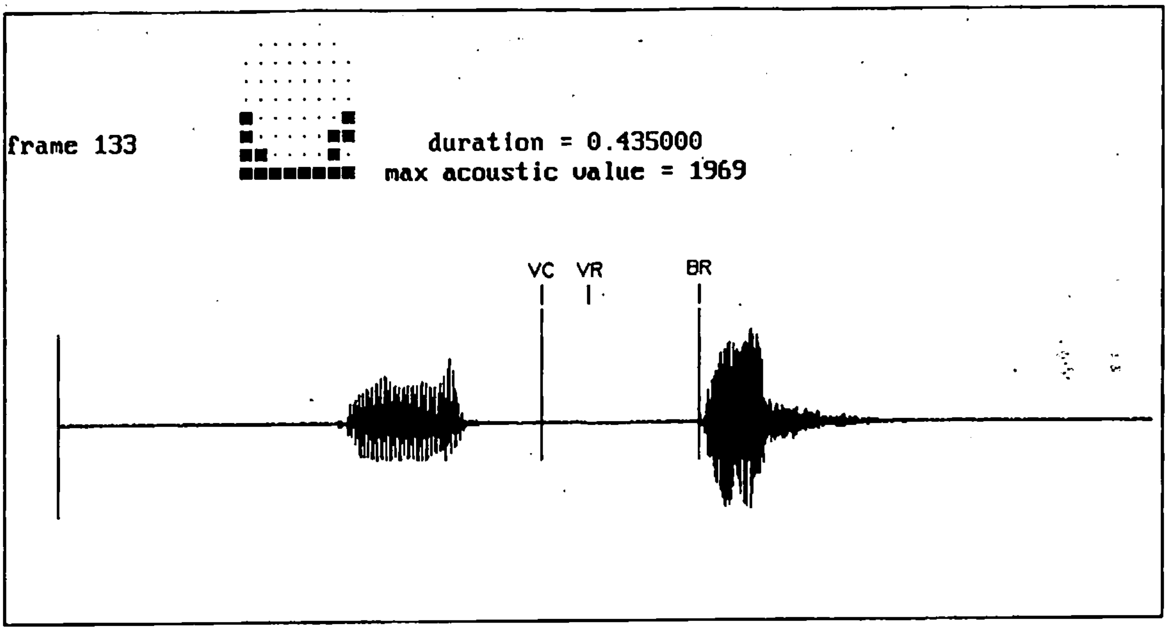


Figure 7-24: Acoustic waveform for the word "brush" 2 produced by CR. VC = velar closure; VR = velar release; BR = bilabial release.

7.6.3 Summary

The MAGs produced by CR were variable in duration and spatial contacts. Duration ranged from 30 to 180 msecs. Whilst the velar MAGs were spatially normal productions for this subject similar in appearance to correct productions, the alveolar MAGs were not typical of correct alveolar plosives for this subject (see Figure 7-20). Two of the words contained the MAG as a target phoneme elsewhere in the word ("witchcraft" 2 and "weekday" 2).

7.7 JM (Broca's aphasic without AOS)

No MAGs were noted during production of the word lists and the repetition task.

7.8 IE (conduction aphasic)

IE produced MAGs on 15 out of the 122 words. Ten were alveolar articulations, four velar, and one was a double alveolar/velar articulation. The words which contained the MAGs, their phonetic transcriptions, the duration of the MAG and their position in the word are all given in Table 7-6.

Target word	Phonetic transcription	Type of MAG	Duration of MAG (msecs)	Word position
gear 2	[tʃiez]	alveolar	140	WI
key 2	[ə tʰi]	alveolar	140	WI
shark 1	[ə t͡tʃɑːt]	alveolar	80	WI
shark 2	[ɔ sʃɑːɹt]	alveolar	100	WI
zoo 2	[dɔ (d) zu]	alveolar	400	WI
squashkit 1	[dɔ skwɒstiːt]	alveolar	60	WM
kitkat (rep 2)	[ɔ tʰɪtkæt]	alveolar	130	WI
kitkat (rep 7)	[ɔ g̊'tʰɪdkæt]	alveolar	180	WI
squashkit 2	[dɔ skwɒtki't]	alveolar	110	WM
car* 2	[ɔ kʰ/kʰ/kʰɑɹz]	alveolar	20	WI
beak 2	[ɔ (d) bit]	velar	60	WI
skirt 2	[dɔ skɜɔlt]	velar	70	WI
deer 2	[ɔ g̊ɔ ɔ diɔ]	velar	90	WI
tractor 1	[dɔ kɹæktɔ]	velar	30	WI
book 2	[dɔ buk]	double velar/alveolar	?	WI

Table 7-6: Target words produced by IE where MAGs were detected on analysis of the EPG data. The corresponding phonetic transcription, type of MAG, duration and position of the MAG are given. The duration of the MAG in "book" could not be determined since there was no full closure for the velar articulation and no indication from the acoustic trace since it was simultaneously articulated with the bilabial plosive. Full alveolar closure was not made for the item marked with an asterisk (*).

7.8.1 Alveolar MAGs

The phonetic transcriptions indicate that all of the alveolar MAGs were detected through auditory analysis. Prior to the analysis of the EPG data many of these were felt to be phonemic paraphasic errors, for example, "key" 2 was heard and transcribed as an alveolar plosive ("key" 2 → [ɔ tʰi]). However, examination of the lingual/palatal contact patterns revealed that this was not a pure substitution. Instead IE articulated a velar prior to and simultaneously with the alveolar. The velar was released first thereby leaving a single alveolar articulation. This was a spatially consistent feature for all words with a target WI velar plosive ("gear" 2, "key" 2, "kitkat" repetition 2, "kitkat" repetition 7). For all bar "kitkat" (repetition 7) a single alveolar plosive was heard and transcribed. The lingual/palatal contact patterns for "key" are shown in Figure 7-25.

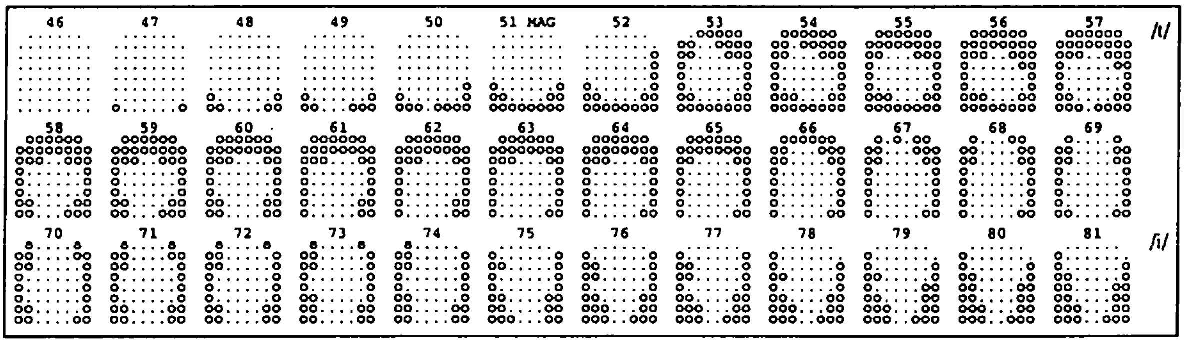


Figure 7-25: EPG print-out of the word "key" 2 produced by IE which was transcribed as [ə tʰi]. Velar closure can be seen prior to the alveolar closure which was detected through auditory analysis.

A clear velar closure can be seen from frames 51 to 56 inclusive. The alveolar articulation which is detected auditorily commences at frame 53 and is held for 140 msecs. The result is a period of double velar/alveolar articulation (40 msecs, frames 53 to 56 inclusive). Both alveolar and velar patterns appear spatially normal. The temporal arrangement of the velar and alveolar articulations were similar for three of the words, "key" 2, "gear" 2, and "kitkat" (repetition 7). For these words the velar commenced either 10 or 20 msecs prior to the alveolar. The velar was consistently shorter in duration than the following MAG (between 60 and 100 msecs). In contrast in "kitkat" (repetition 2) the velar commenced 70 msecs prior to the alveolar closure and this was approximately the same duration as the alveolar MAG (velar = 140 msecs, alveolar MAG = 130 msecs).

The alveolar MAGs were detected through auditory analysis for two of the three words with a target WI alveolar or post alveolar fricative ("shark" 1 and "zoo" 2). EPG print-out of "shark" 2 in which the MAG was not detected through auditory analysis is shown in Figure 7-26. Full alveolar closure commences at frame 62 and is maintained for 80 msecs. This is released into a post alveolar fricative. Whilst there appears to be few lateral contacts for the fricative this is considered spatially normal for this aphasic speaker. IE produces a second spatially normal alveolar plosive in WF position which is detected through auditory analysis and therefore considered a substitution rather than a MAG. Lingual/palatal contact patterns for the WI MAG and WF substitution are spatially similar.

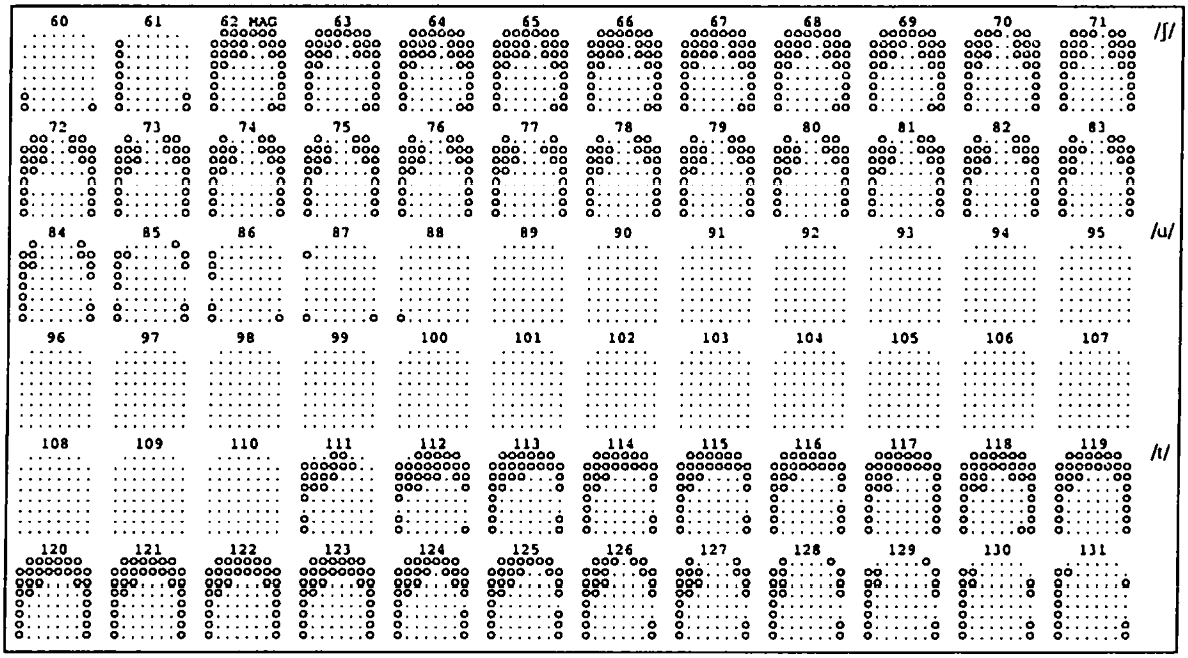


Figure 7-26: EPG print-out of the word "shark" 2 showing WI alveolar MAGs and WF alveolar substitution produced by IE. The word was phonetically transcribed as [ə sʃa:ɹt].

The MAG in "shark" 1 is different to the patterns shown in Figure 7-26 because IE initially produces the target fricative which is held for 40 msecs before making full alveolar closure (MAG) and then returning back to the post alveolar fricative (see Figure 7-27). Fewer lingual/palatal contacts are made during this MAG compared to those in Figure 7-26. The MAG in Figure 7-27 may be an overshoot of the target /ʃ/ since the MAG and the target fricative /ʃ/ only differ in the number of contacts along row 1. This was also suggested for the alveolar MAG produced by HL during production of the word "shark" (see Figure 7-41). In WF position a voiceless alveolar plosive was heard and seen from the EPG data.

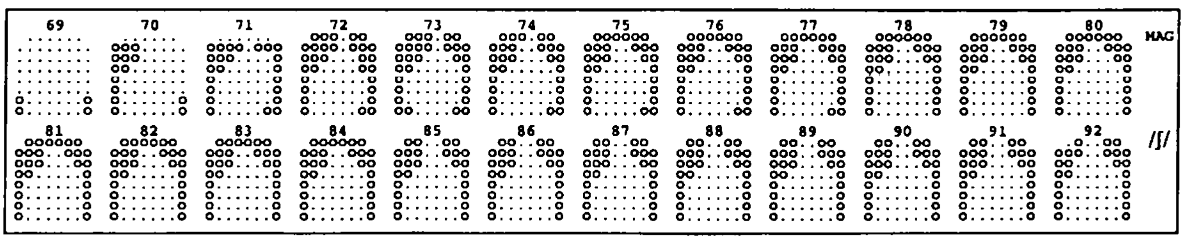


Figure 7-27: EPG print-out of the WI alveolar MAG in "shark" 1 produced by IE. The word is heard as [ə t͡ʃa:t].

The alveolar MAG in "zoo" is similar to that in "shark" 2 since full alveolar closure was made prior to the alveolar fricative. However the duration of the alveolar MAG was much greater (400 msecs). This may have been due to perseveration of the word "the" which was produced as [dɔ]. Once again the alveolar MAG appeared spatially normal for this speaker.

The WM alveolar MAGs detected during productions of the word "squashkit" were spatially very similar. Both occurred prior to the WM fricative but only one was detected through auditory analysis in this position ("squashkit" 1 → [dɔ skwɒsti:t], "squashkit" 2 → [dɔ skwɒtki't]. The corresponding EPG patterns for these WM MAGs are shown in Figure 7-28 and Figure 7-29 respectively.

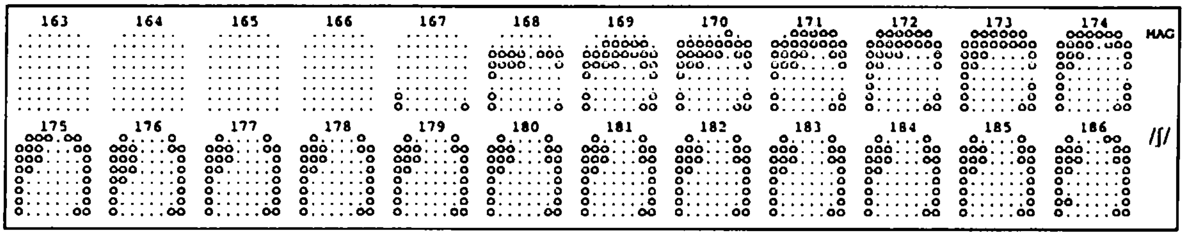


Figure 7-28: EPG print-out of the WM MAG produced by IE during production of "squashkit" 1 heard as [dɔ skwɒsti:t].

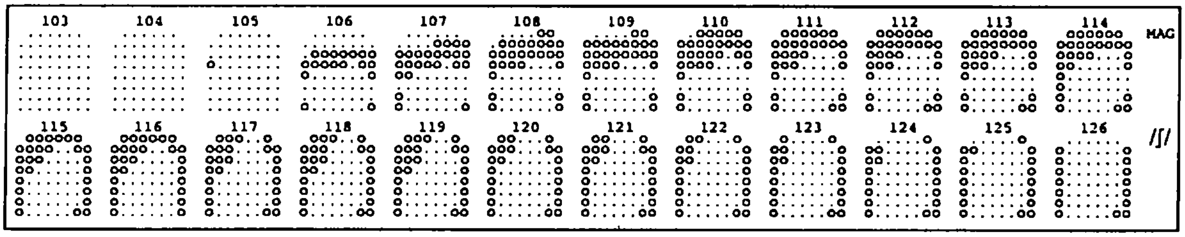


Figure 7-29: EPG print-out of the WM MAG produced by IE during production of "squashkit" 2 heard as [dɔ skwɒtki't].

The EPG sequences shown in Figure 7-28 and Figure 7-29 show full closure preceding the fricative. Both start by making closure in rows 3 and 4 which advances forwards to a more usual position of lingual/palatal contacts for an alveolar plosive. These WM alveolar MAGs could again be an overshoot of the target /ʃ/.

Phonetic transcription for the target word "car" 2 indicated WI phoneme repetition. However, analysis of the EPG data only identified one velar closure prior to the WI target. Following this there was a very brief alveolar closure (20 msecs) before the target velar articulation was made. During production of the target velar plosive an alveolar MAG was seen on the EPG print-out. The alveolar leading into the target velar is shown in Figure 7-30.

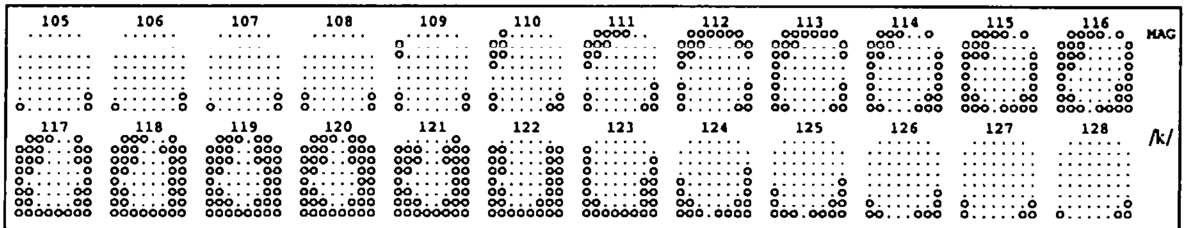


Figure 7-30: EPG print-out showing WI velar plosive and preceding alveolar MAG produced by IE during the word "car" 2. Full alveolar closure can be seen to commence at frame 112. This was detected as a WI phoneme repetition on auditory analysis. The production was heard as [ɔ k^h/k^h/k^hɑːz].

Full velar closure for the target WI velar commences at frame 117 and is held for 70 msecs. Prior to the target velar IE makes alveolar contact which reaches full closure at frames 112 and 113. This is then released and some of the contacts in rows 2 and 3 are removed. However contacts in rows 2 and 3 increase (frame 117) during velar closure although full alveolar contact is not made. It is unclear whether this is a continuation of the alveolar articulation that commenced in frame 111 or whether this is a repetition of the alveolar. Auditorily the alveolar was detected prior to the velar target. Since its release was heard it may be that the alveolar MAG made simultaneously with the WI target velar is a separate articulation.

7.8.2 Velar MAGs

All the velar MAGs occurred in WI position when either a single consonant or a cluster was expected. Whilst three of the four MAGs were detected auditorily, analysis of the EPG print-out again revealed information that was not available to the listener. For example, an alveolar was heard prior to the WI bilabial plosive during production of the word "beak" 2. However, on analysis of the EPG patterns this perceived alveolar articulation actually appeared to be a spatially normal looking velar plosive with no alveolar contacts. A spatially typical alveolar plosive was seen from the EPG trace in WF position and was also detected through auditory analysis (i.e. a substitution). This may have influenced the perception of the MAG in WI position.

The phonetic transcription of "a deer" 2 indicates an initial attempt at the word that was corrected |ɔ gə ə diə|. This velar gesture was easily identified on the EPG print-out, occurring some 600 msecs prior to the target /d/. However, analysis of the EPG patterns for the second attempt at the WI alveolar which was perceived as a normal production revealed the presence of some inappropriate velar contacts (see Figure 7-31 below). This is similar to the target word "car" 2 where repetitions were detected prior to the WI plosive. On final realization of the target WI phoneme a MAG was detected through analysis of the EPG contact patterns (Figure 7-30).

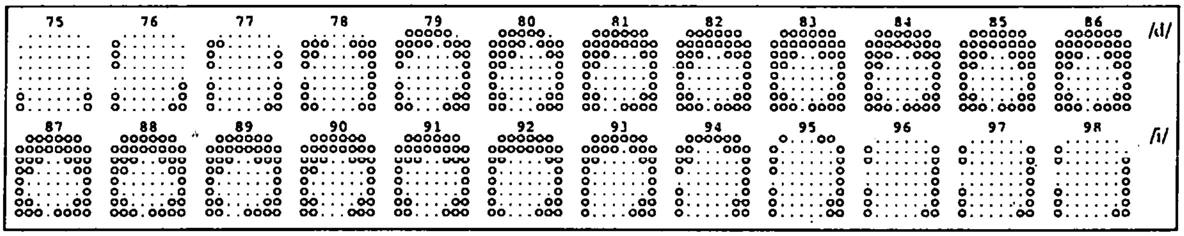


Figure 7-31: EPG print-out of the WI target /d/ and velar MAG in "deer" 2 produced by IE heard as /ɔ gɔ ə diə/.

The EPG print-out shows an increase in velar contacts which would be considered normal for a velar plosive (if there was no simultaneous alveolar closure). These occurred following alveolar closure and the velar MAG is released before the alveolar plosive. The result is a period of double alveolar/velar articulation.

The velar MAG in "skirt" 2 was undetected through auditory analysis. However, through inspection of the EPG data for the WI cluster velar contacts were seen prior to the fricative /s/. These were spatially normal for a velar plosive although different to the /k/ that followed the WI fricative. The MAG had fewer contacts and no complete velar closure.

The MAG in WI position of "tractor" 1 was detected through auditory analysis as a substitution (|k| for /t/). Analysis of the EPG data revealed the presence of an alveolar in addition to the velar although this was not considered a normal production for an alveolar plosive. The lingual/palatal contact patterns for the WI cluster are given in Figure 7-32.

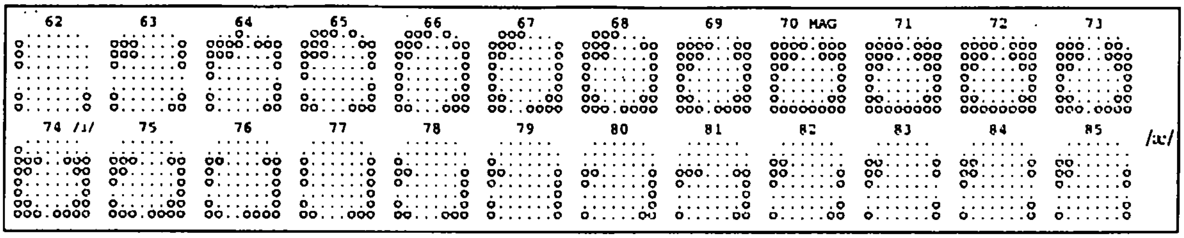


Figure 7-32: EPG print-out of the WI cluster in "tractor" 1 produced by IE heard as [də kɹæktə].

Alveolar contacts start at frame 63 but these are not spatially normal for an alveolar plosive. The contacts move forwards on the palate until frame 68 when they retract and stabilize for five frames. Simultaneous with this IE makes full closure in the velar region which is spatially normal for a velar plosive. Only the velar is detected through auditory analysis. Although a velar articulation is heard and phonetically transcribed in WM position, no velar contacts were seen on analysis of the EPG data. Therefore this WI velar MAG may be a result of faulty timing, that is the WM velar has been articulated too early.

7.8.3 Double velar/alveolar MAG

A double velar/alveolar articulation was seen in WI position during production of the word "book" 2 but was undetected through auditory analysis. Phonetic transcription suggested an error free articulation ([ðə buk]). The EPG patterns for the word "book" 2 are shown in Figure 7-33 and the corresponding waveform in Figure 7-34.

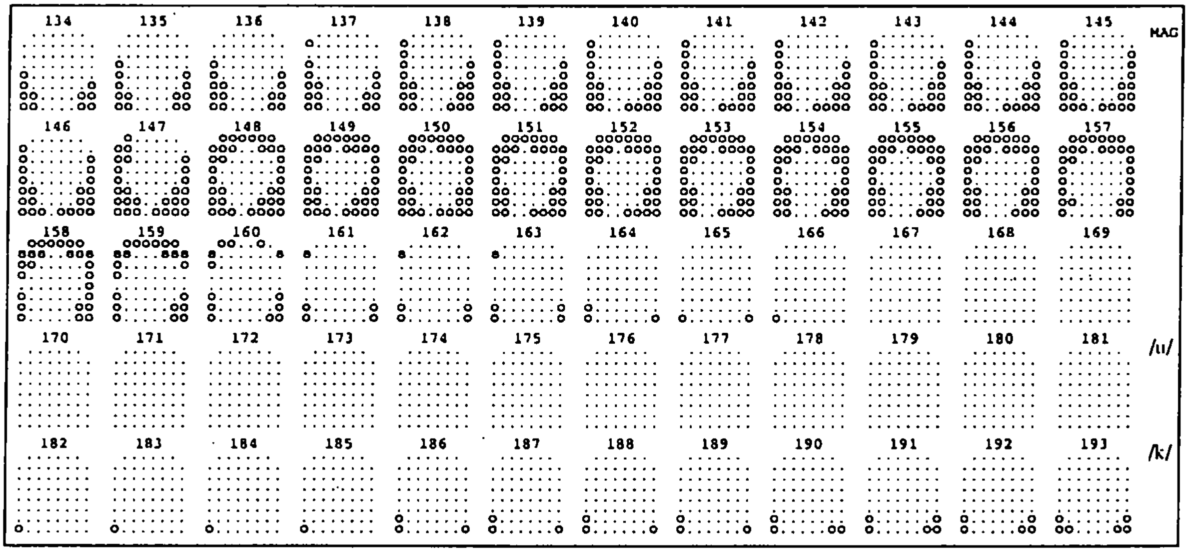


Figure 7-33: EPG print-out of the word "book" 2 produced by IE. The word was heard as [ðə buk].

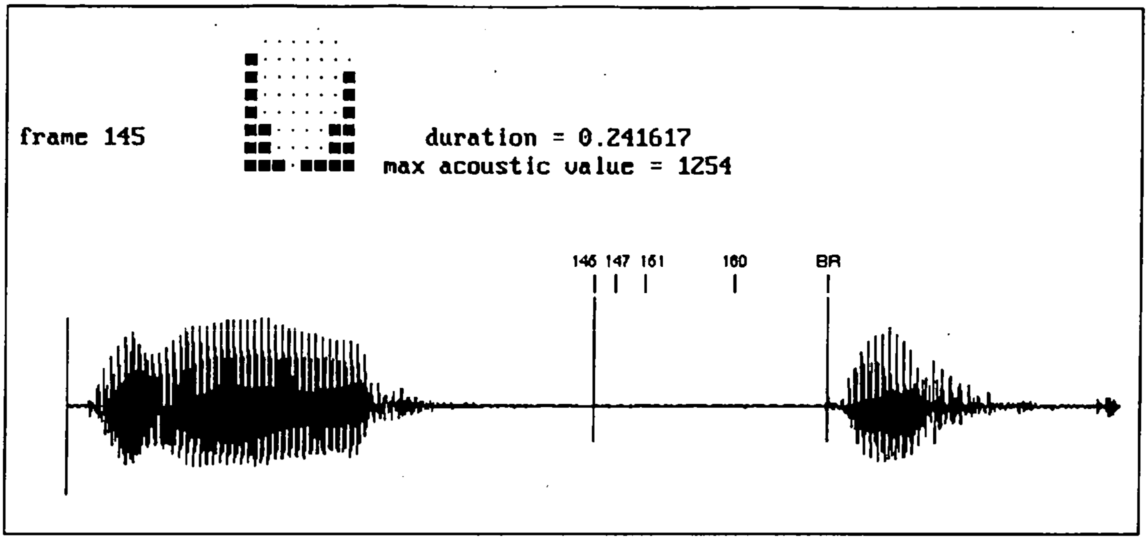


Figure 7-34: Acoustic waveform of the word "book" 2 produced by IE. Frames corresponding to the EPG print-out are shown in Figure 7-33. The point of bilabial release, as detected from the acoustic signal, is marked BR.

During closure for the target bilabial stop IE makes both velar and alveolar EPG contacts. Although full closure is not made for the velar this is considered spatially normal for a velar plosive. A period of double articulation can be seen from frames 148 to 150 inclusive. The velar and alveolar contacts are released prior to the bilabial plosive which is presumably why they are undetected through auditory analysis.

Frame numbers are marked on the acoustic trace in Figure 7-34 and correspond to the EPG contact patterns in Figure 7-33. They indicate the temporal position of the velar and alveolar lingual/palatal contacts during the bilabial closure.

7.8.4 Summary

The MAGs produced by IE were variable in duration ranging from 20 msecs to 400 msecs. Velar MAGs tended to be shorter than alveolar and were less frequent in the data. The majority of the MAGs were in WI position (13/16) and were spatially normal for this speaker. All of the alveolar MAGs were detected through auditory analysis. However, they were sometimes mistakenly identified as pure substitutions (paraphasias) when the EPG data actually revealed double articulations (the MAG plus the target phoneme). Velar MAGs were either not detected through auditory analysis or misidentified. Eight of the words in Table 7-6 contained the MAG elsewhere in the word.

7.9 PW (conduction aphasic)

This subject produced three MAGs which were all alveolar in appearance. The words, the position of the MAG in the word, the phonetic transcription and duration of the MAG are given in Table 7-7.

Target word	Phonetic transcription	Type of MAG	Duration of MAG (msecs)	Word postion
gear 2	[ə g̚ giɾ]	alveolar	210	WI
book 1	[ə b:uk]	alveolar	250	WI
squashkit 2	[ə skwɔʃ.kɪt]	alveolar	430	WM

Table 7-7: Target words produced by PW where MAGs were detected on analysis of the EPG data. The corresponding phonetic transcription, type of MAG, duration and position of the MAG are given.

Only "squashkit" 1 contained a target alveolar plosive. The MAGs varied in their duration ranging from 210 to 430 msecs. The phonetic transcriptions indicate that for "gear" 2 an intrusive sound was detected in WI position but the phonetic symbol does not reflect the EPG patterns. A clear alveolar articulation was not identified through auditory analysis for any of the target words where MAGs occurred.

In "gear" 2 closure was made in the alveolar/palatal region prior to velar closure which appeared spatially abnormal since it is slightly retracted. The MAG was not released until 130 msecs after the onset of full velar closure. Therefore there was a period of double alveolar/velar articulation. The EPG patterns for this sequence can be seen in Figure 7-35. A correct target alveolar plosive articulation during production of the word "tear" can be seen in Figure 7-36.

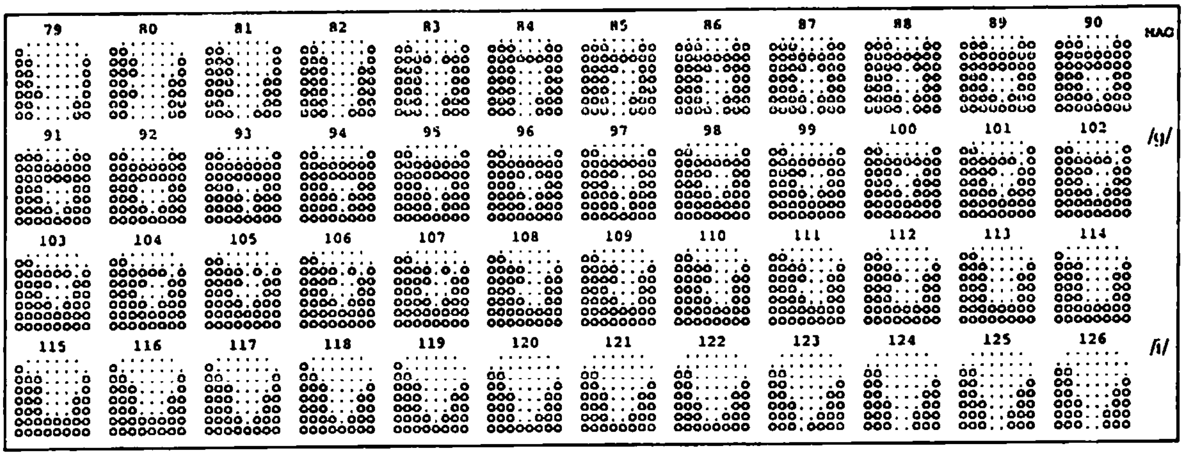


Figure 7-35: EPG print-out of the WI alveolar MAG in "gear" 2 produced by PW. The word was heard as [ɔ g'gir].

Full closure is first seen in frame 84 along row 3. In frame 89 velar closure is made and there is also closure along row 4 in addition to row 3. This double articulation which is probably best described as palatal/velar is maintained until frame 101 although full release in the palatal region is not until frame 105. This sequence is similar in appearance to some of the MAGs produced by MU where an alveolar MAG was frequently seen preceding a WI target velar plosive (see Figure 7-6). Figure 7-36 below shows production of an alveolar plosive which is spatially typical for PW produced during the word "tear". This articulation is made further forward on the palate than the MAG in Figure 7-35 although both are retracted at the onset.

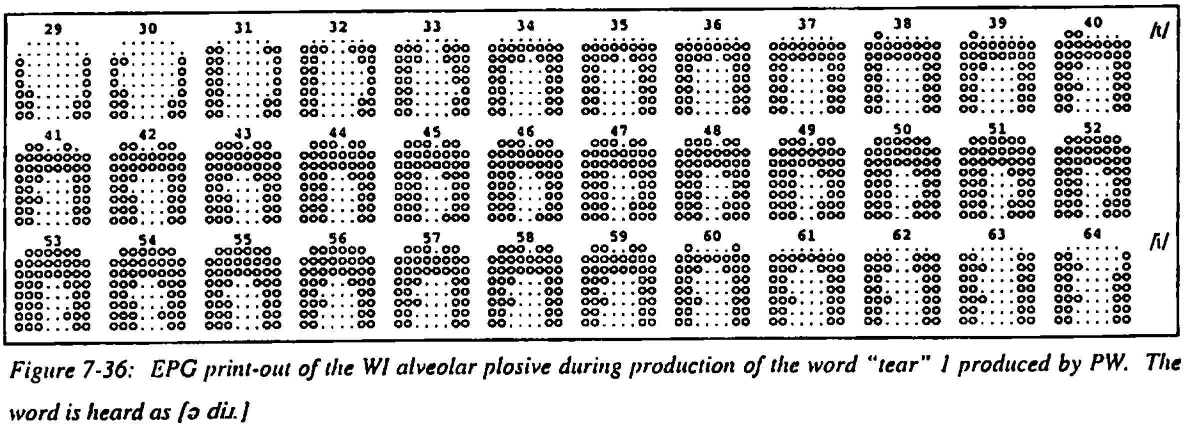


Figure 7-36: EPG print-out of the WI alveolar plosive during production of the word "tear" 1 produced by PW. The word is heard as [ɔ diː]

The alveolar MAG produced during "book" has also been seen in the speech of some aphasics (MU, BA, CR and IE). Similar to earlier examples, this MAG was produced during the bilabial closure and released prior to the bilabial. Therefore a period of double bilabial/alveolar articulation resulted although the alveolar was undetected through auditory analysis.

The alveolar MAG in "squashkit" 2 occurred following articulation of the target post alveolar WM fricative /ʃ/ and before the WM /k/. A period of double alveolar/velar articulation results since the alveolar MAG is not released until 120 msecs following full velar closure. This is similar in appearance to MU where the velar

MAGs in "bookshop" 1 and "deckchair" 1 occurred during the WM consonant sequence (see Figure 7-10). The WM consonant sequence for "squashkit" 2 can be seen in Figure 7-37.

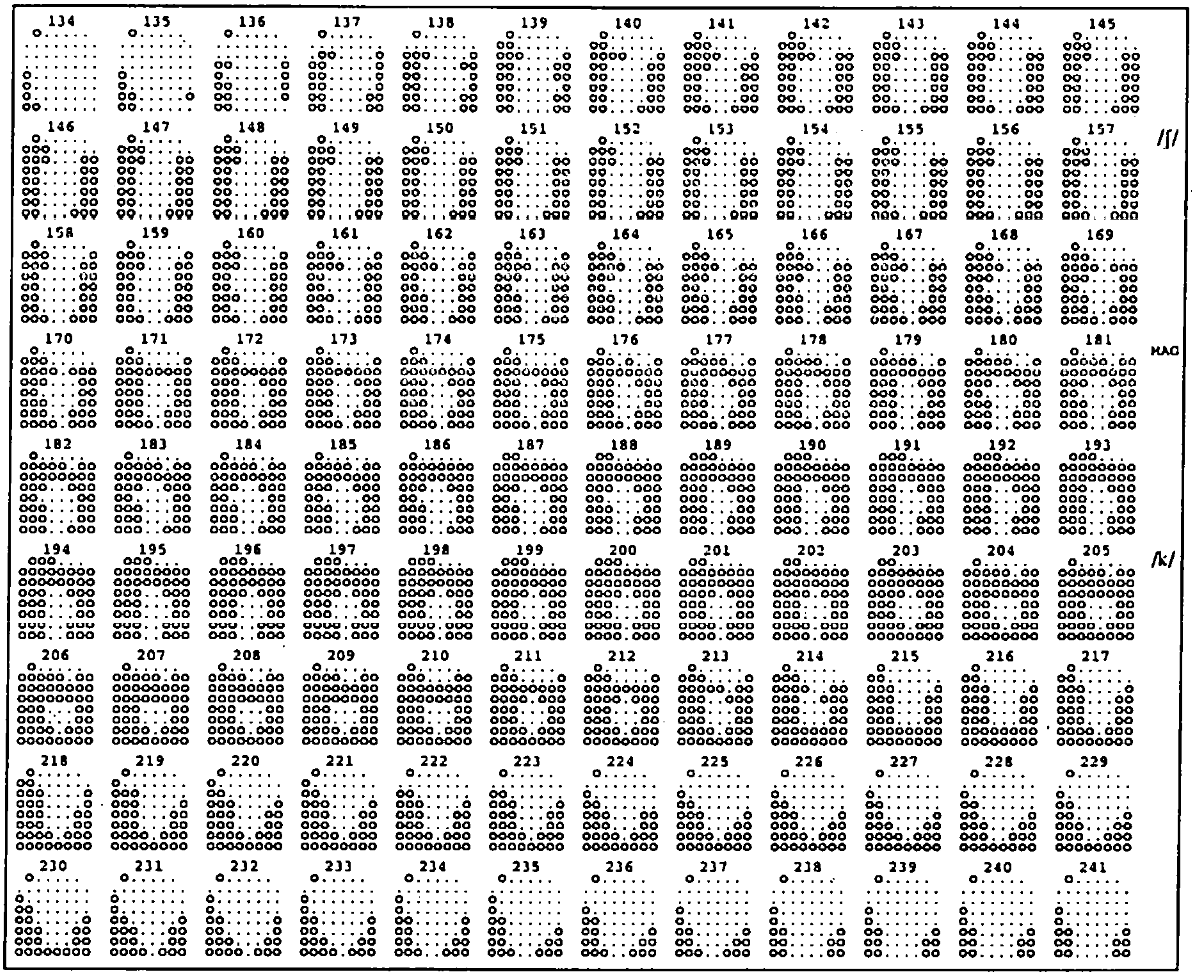


Figure 7-37: EPG print-out of the WM alveolar MAG in "squashkit" 2 produced by PW transcribed as [ə skwɔʃ.kɪt].

The alveolar closure which starts at frame 171 may be an overshoot of the target /ʃ/ and not an MAG. If this is true the syllable final within word consonant would be considered excessively long in duration. This MAG or overshoot is undetected through auditory analysis although the phonetic transcription indicates a brief pause between the post alveolar fricative and the velar plosive. This is possibly an unreleased stop which is detected as a pause in the sequence of phonemes.

7.9.1 Summary

All the MAGs detected in the speech of PW involved the anterior portion of the palate. These were more retracted than the alveolar MAGs noted in the speech of the other aphasics and not typical of a correct alveolar plosive for PW. Two of the MAGs occurred in WI position and none were correctly identified through auditory analysis. No velar MAGs were noted during production of the word lists or repetition tasks.

7.10 FC (anomic)

Two MAGs were identified through analysis of the EPG data for FC. Both of these were velar articulations occurring in WI position but only one was detected through auditory analysis. FC produced a MAG where a single target bilabial was expected. The MAG was detected through auditory analysis since it was produced prior to the bilabial plosive and not simultaneously with it. The EPG patterns for the word "book" 2 can be seen in Figure 7-38.

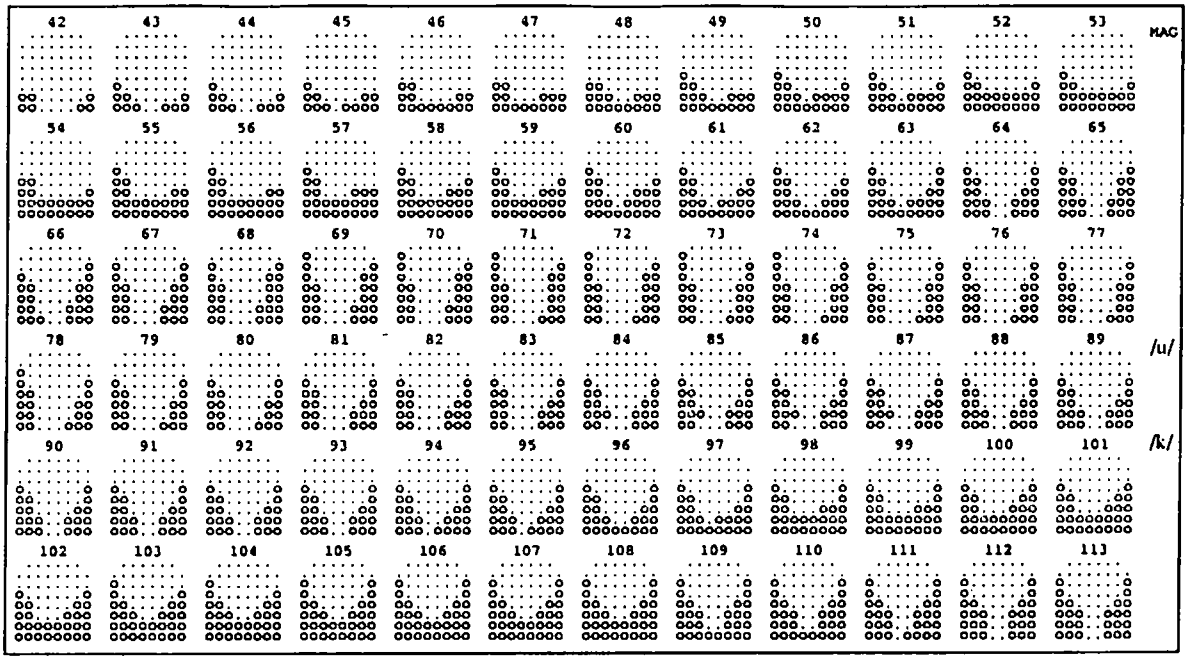


Figure 7-38: EPG print-out of the word "book" 2 showing WI MAG and WF target /k/produced by FC. The word was phonetically transcribed as [ʌ gˈ buk].

Full velar closure commences at frame 46 and is maintained until frame 63 (180 msecs). The spatial configuration of the MAG closure period is very similar to the WF velar target (see frames 96 to 110) although the approach phase is different. The difference in the approach is probably a result of the different vowel preceding the MAG compared to the WF /k/. Both gestures are of similar duration (MAG 180 msecs, target /k/ 150 msecs).

The second MAG occurred during the word "dolls" 2 where there was no target velar. Closure was made prior to the alveolar target and released following full closure for the WI /d/. The MAG is spatially unusual for several reasons. Firstly, full closure is made along row 7 initially and this then spreads to include rows 6 and 8. Full closure along three rows for a velar articulation is not typical for FC or normal speakers. Furthermore there appears to be an excessive amount of contacts along the lateral margins. The release is also unusual in that the contacts in row 7 are maintained longer than row 8. The MAG is shown in Figure 7-39. Figure 7-40 shows a normal velar gesture preceding a back vowel in WI position produced by FC for comparison (target word "cocktail" 2).

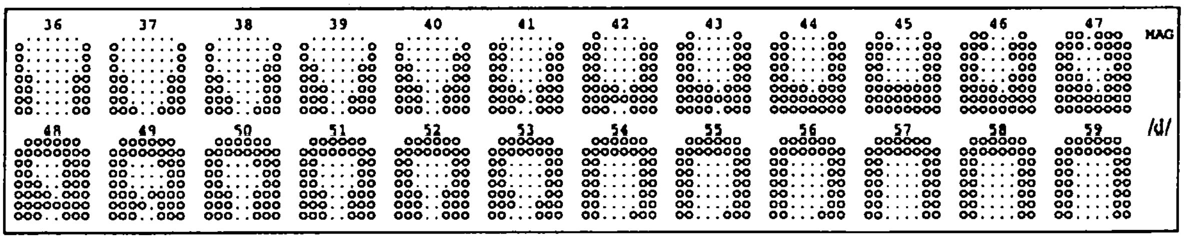


Figure 7-39: EPG print-out of the MAG in "dolls" 2 produced by FC prior to the WI /d/. The word is heard as [ðə dɔlz].

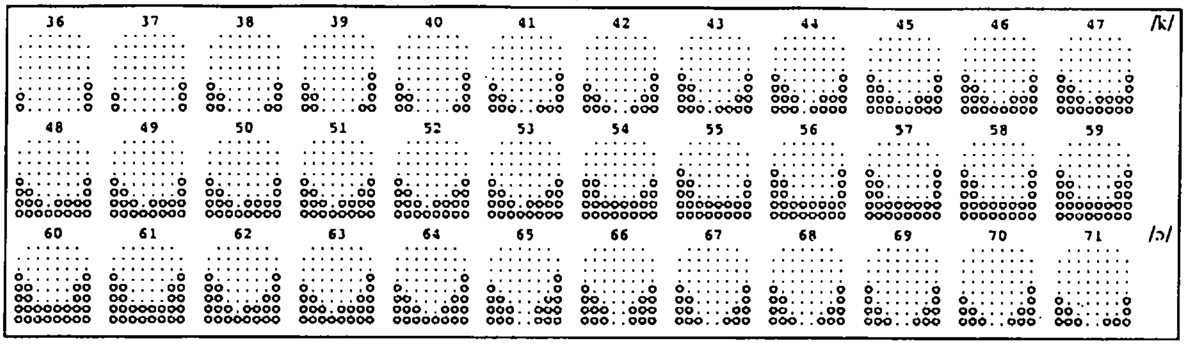


Figure 7-40: EPG print-out of WI /k/ in "cocktail" 2 produced by FC. This correct production was heard as [ʌ kʰɔkˈtel].

Comparison of the velar contacts in Figure 7-39 with the target velar in Figure 7-40 highlights the increased number of contacts in the velar, palatal and alveolar regions of the palate for the MAG. Approach and release phases are also different.

7.11 HJ (anomic)

This aphasic speaker produced no MAGs during production of the word lists or repetition task.

7.12 HL (anomic)

HL produced two alveolar MAGs and one velar MAG (see Table 7-8). Two of the MAGs were audible, in WI position and prior to an alveolar fricative ("shark" 1 → [ə tʃ:ʃaɹk], "skirt" 2 → [əˈskɜɹt]). However, the phonetic transcription for the MAG in "skirt" 2 indicated an alveolar plosive prior to the alveolar fricative but on inspection of the EPG data a velar MAG, not an alveolar, was evident. Both these MAGs were corrected.

Alveolar MAGs				Velar MAGs			
Target	Phonetic transcription	Duration of MAG (msecs)	Word position	Target	Phonetic transcription	Duration of MAG (msecs)	Word position
shark 1	[ə tʃ: ʃaɹk]	350	WI	skirt 2	[əˈskɜɹt].	90	WI
book 1	[ə buk]	70	WI				

Table 7-8: Target words produced by HL where alveolar and velar MAGs were detected through analysis of the EPG data. The corresponding phonetic transcriptions, duration of the closure period and position of the MAG are given.

The first example is possibly an overshoot of the target /ʃ/ since the articulation for the target /ʃ/ and the MAG differed only in rows one and two where full closure was made instead of a narrowing for air to be channeled through. Rows 3 to 8 are identical in appearance and demonstrate a characteristic skewed pattern for the target and the MAG (see Figure 7-41). The approach to the MAG is similar spatially to the target /ʃ/ (for example compare rows 1 and 2 in frame 46 with the same rows in 90 and 91) but it is shorter in duration. Since the MAG is not released and then rearticulated it seems that this MAG may be an overshoot of the WI target phoneme, something usually associated with dysarthric speech and identified by Hardcastle et al. (1985).

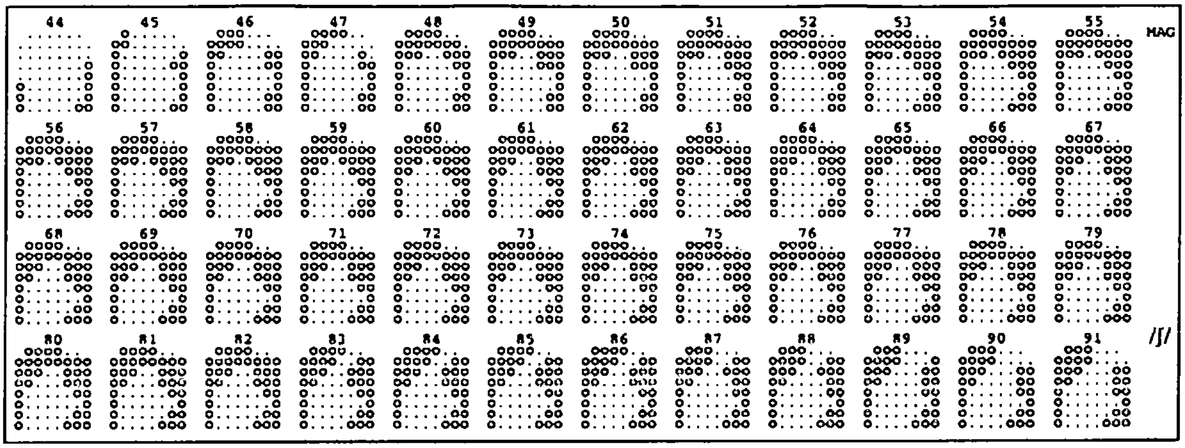


Figure 7-41: EPG print-out of the WI MAG in "shark" 1 produced by HL. The word is heard as /ə tʃ: ʃɑɹk/.

The MAG in "skirt" 2, heard as an alveolar but shown in the EPG patterns to be a velar, can be seen in Figure 7-42.

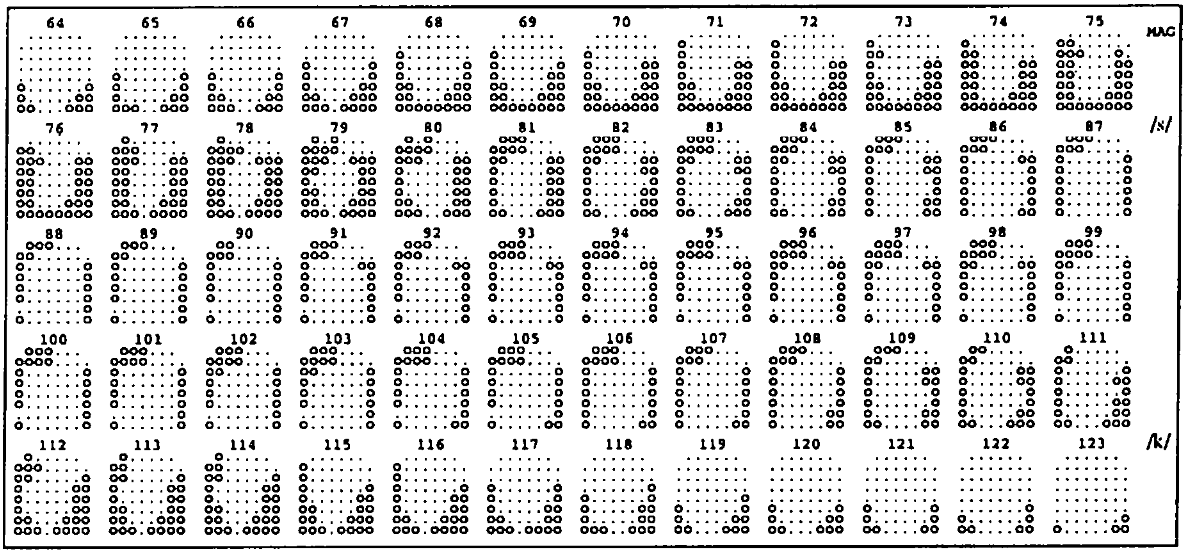


Figure 7-42: EPG print-out of the WI velar MAG heard as an alveolar produced by HL during the word "skirt" 2. The word was phonetically transcribed as /ə ʔskɜɹt/.

The MAG in Figure 7-42 has a greater number of lingual/palatal contacts than the target velar in the WI consonant cluster. However, direct comparison of these two articulations is difficult since we cannot estimate how many of the contacts are a result of either anticipatory or perseveratory coarticulation. The velar MAG appears to be of greater duration than the target velar.

HL also produces a MAG in WI position during production of the word "book" 1. This appears to be a spatially normal alveolar plosive but it is undetected through auditory analysis. This is presumably because the MAG is articulated simultaneously with the bilabial plosive but released prior to the WI target /b/. The resulting articulation is therefore a double alveolar/bilabial gesture. The EPG print-out of the word "book" is shown in Figure 7-43. The approach and the release phase to the MAG appear normal as does the spatial arrangement of the resulting articulation. Furthermore, the EPG contact patterns for the rest of the word are considered to be spatially appropriate. Therefore this appears to be an isolated misarticulation. It is shorter in duration when compared to the other alveolar MAG produced by HL, being maintained for only 70 msecs (compare the MAG in "shark" which is 350 msecs).

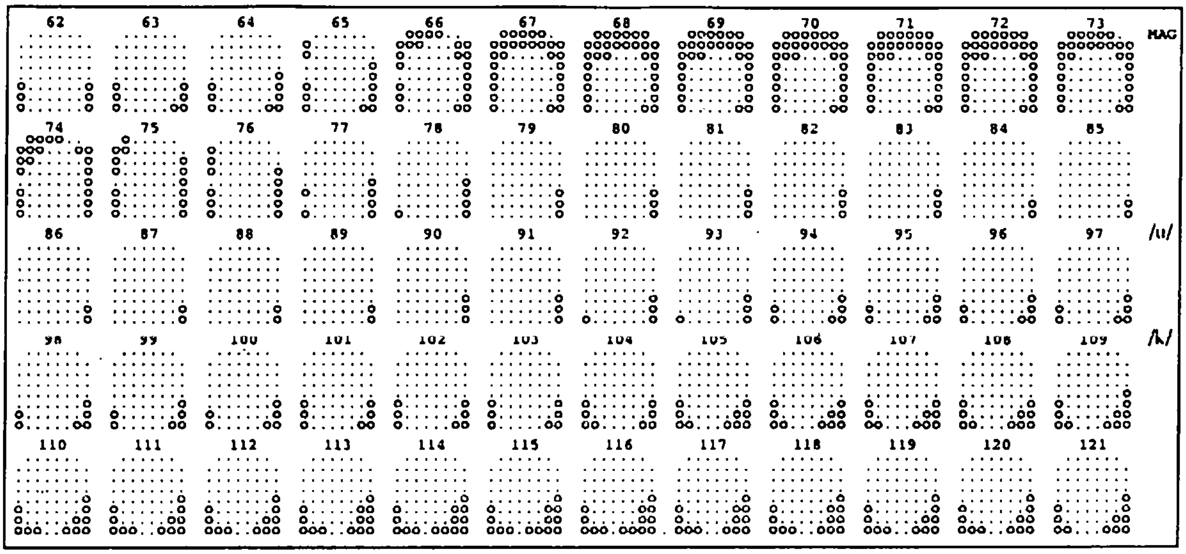


Figure 7-43: EPG print-out of the word "book" / showing the WI alveolar MAG produced by HL. The word is heard as /ɔ buk/.

7.12.1 Summary of MAGs produced by all aphasic subjects

Both regularities and irregularities were noted during the production of MAGs. These are summarized below and will be discussed in Chapter 8.

1. Alveolar MAGs were over three times as frequent as velar.
2. The incidence of MAGs did not appear to be related to the aphasic syndrome but instead subject specific. However as a group the anomic speakers produced the fewest MAGs.
3. Most MAGs occurred in WI position (65/77 = 84%).
4. Approximately 75% of MAGs were undetected through auditory analysis.
5. The majority of MAGs were spatially normal. Only PW produced lingual/palatal contacts which were consistently different to correct productions.
6. The MAGs identified appear to fall into two distinct categories: spatially normal alveolar or velar gestures which occurred where the target articulation was a bilabial, alveolar or velar plosive; and distorted fricatives which may be regarded as overshoots of the target gesture due to deficits in motor control.
7. During the repetition tasks, MU (Broca's aphasic with AOS) frequently produced an alveolar gesture in addition to the target velar plosive. The alveolar was produced prior to the velar in eight out of twelve productions of "clock" and six out of twelve attempts at "kitkat". Whilst the temporal arrangement varied, it appeared that the velar target was often triggered by the production of an alveolar MAG.
8. For IE (conduction aphasic), if an alveolar MAG was detected during the production of a target velar, the velar was consistently produced first followed by the MAG. Therefore the velar/alveolar sequence appeared to be a coordinated structure. This pattern is the reverse of the spatial sequencing noted in point seven (above) for MU.

Chapter 8

8. Discussion

8.1 Introduction

In this thesis the technique of electropalatography has been used to identify errors in the speech of aphasic subjects which were indicated by an auditory-based analysis and also errors which were not. Errors such as the so-called misdirected articulatory gestures (MAGs) are of interest because they assist in the continued development of models of speech production. The models must be able to account for such errors or be modified so that they can explain their occurrence in disordered speech. If a model of speech production is unable to account for these error patterns then the credibility of the model is questioned.

In this thesis a large data set was collected from ten aphasic speakers variously diagnosed as Broca's with AOS, Broca's without AOS, conduction and anomic aphasics, who, through auditory based analysis, were shown to be demonstrating speech sound errors. In addition ten control speakers were recorded producing the same corpus of data which enabled comparison between two groups of equal size. Therefore this study has considerably expanded the amount of normative EPG data which was previously available. Through analysis of the EPG patterns, errors in lingual/palatal contacts, the sequencing of gestures produced by the aphasic speakers and variability of productions were identified. Many of the errors have never been noted in the speech of normal subjects. These differences provide an excellent opportunity to speculate on the level of impairment in the aphasic speaker.

This chapter aims to:

1. Discuss additional information that the EPG data brings to a perceptual based analysis and highlight the discrepancies between the two types of analyses.
2. Try to account for the MAGs that were identified in the aphasics' speech within the models of speech production outlined in Section 2.6 and suggest modifications to these models when the errors cannot be explained.
3. Discuss the ability of the aphasic speaker to coarticulate and provide explanations for intra- and inter-subject differences within the aphasic subjects and between the aphasic and control groups.
4. Relate differences in the variability of aphasic and normal speech to current theories of speech production.
5. Highlight the methodological limitations of the present investigation and suggest areas for future research.

8.2 Auditory-Based Analyses

There have been several studies which have used auditory-based analysis alone as a method for investigating the speech of aphasic speakers (Blumstein, 1973; Canter et al., 1985; Mackenzie, 1982; Odell et al., 1991; Miller, 1995). Whilst Blumstein's (1973) systematic characterization of phonological error patterns in Broca's, conduction and Wernicke's patients did not reveal consistent differences between the subtypes, Canter et al. (1985), Mackenzie (1982), and Odell et al. (1991) claimed that various aphasic syndromes could be differentiated on the basis of a perceptual analysis. This investigation supports the claims of Blumstein since auditory-based analysis of errors did not allow the consistent differentiation of aphasic patients. Those patients who had been grouped together using a traditional classification scheme following standardized assessment (BDAE) were not consistent in their error types or frequencies. For example, 24.59% of errors for one Broca's aphasic with AOS (FM) were classified as errors of substitution compared to 64.91% for MU (also a Broca's aphasic with AOS) (see Table 5-8, Chapter 5). Similarly, the proportion of substitution errors produced by PW (conduction aphasic) was 33.33% compared to IE, also a conduction aphasic, where 60% of his errors were classified as substitutions. These findings would appear to support Blumstein's (1973) claim that there is a "systematic disorganization of phonology independent of lesion site" (p.47). Blumstein (1995) suggests that whilst phonological patterns are similar phonetic deficits are more selective.

Canter et al. (1985) in their study of 10 Broca's patients with AOS and 10 paraphasic speakers (5 conduction and 5 Wernicke's aphasics) found that there were more addition errors (e.g. [lift] for /lif/) produced by the paraphasic speakers. This finding was not supported by the data collected in this thesis. The proportion of addition errors produced by the two subjects diagnosed with AOS in this study were 24.59% (FM) and 15.79% (MU). The proportion of addition errors produced by the conduction aphasics IE and PW, (an aphasic syndrome where the speech is characterized by phonemic paraphasias according to Palumbo, Alexander and Naeser, 1992) was 18.18% and 50% respectively (see Table 5-8, Chapter 5). Therefore whilst PW produces over twice as many errors of addition than either of the subjects diagnosed with AOS which would appear to support the claims of Canter et al. (1985), IE produces far fewer.

Therefore from the auditory-based analysis of speech sound errors in this thesis subjects could not be differentiated on the basis of the type or frequency of errors made, a claim that has been suggested from the results of several earlier investigations (Canter et al., 1985; Mackenzie, 1982; Odell et al. 1991). However, it does support the view of Canter et al. (1985) that there is considerable heterogeneity within aphasic groups.

Whilst different researchers have proposed opposing views on the ability of auditory-based analysis to reveal differences between the aphasia syndromes, the current investigation highlighted that the results were dependent on the perceptual classification scheme adopted and also suggests that methodological issues such as subject selection, time since onset, test material etc. should be considered. Analysis of the data using the classification scheme adopted by Mackenzie (1982) and a new taxonomy suggested by the author revealed large discrepancies in the results of the data analysis. Therefore whilst some studies appear to have been replicated by different researchers it would appear that the results from this study undermine whether this is in fact true. It would seem that generalizations are not valid when comparing data using different methods of classification and very different subject selection criteria procedures.

8.3 Substitution Errors

Differential diagnosis of aphasia syndromes has often been concerned with the type of error which characterizes different syndromes. There has been much disagreement as to the most common error type for different disorders. For example, Itoh and Sasanuma (1984) have suggested that errors of substitution are the most common speech error in AOS but Square, Darley and Sommers (1982) disagree. They propose that distortions are more frequent. Differences may depend on the type of phonetic transcription, broad versus narrow, and the expertise of the transcriber. Furthermore, it has been suggested that categorical errors (substitutions) are favoured over non-categorical (distortions) due to a psychological component associated with auditory analysis (Ziegler and Hoole, 1989). In this thesis it was decided that only substitutions would be examined in any detail. Analysis of these errors identified some differences between phoneme classes and aphasia syndromes.

8.3.1 Order of vulnerability

The phonemes for which substitution errors were identified perceptually appeared to show a uniformity of vulnerability across all aphasic speakers. Whilst there were obviously slight differences in the percentage of errors, all aphasics substituted velar, affricates, post alveolar and alveolar fricatives more frequently than alveolar or bilabial plosives. Table 8-1 summarizes the order of vulnerability for the aphasic speakers as a group and indicates the percentage of errors for each phoneme.

	Most vulnerable →												Least vulnerable
Phoneme	/ʃ/	/g/	/tʃ/	/k/	/z/	/s/	/d/	/f/	/t/	/w/	/b/	/n/	/p,m,l,r,h/
% tage of error	28.1	27.6	23.8	17.8	11	8.8	6.0	5.8	5.2	3.3	2.8	1.3	0

Table 8-1: Phoneme order of vulnerability for substitution errors identified through perceptual analysis for all aphasic speakers.

The phonemes which were perceived to be the most vulnerable for substitution were post alveolar fricatives, velar plosives and affricates. The types of substitution for different classes of phonemes were not identical. Fricative substitutions involved both place, manner and voicing depending upon the phoneme target. /s/ and /z/ usually retained the place of articulation (97.4%), with substitutions being characterized by errors of voicing. In contrast, substitution of /ʃ/ most frequently involved place of articulation (/ʃ/ → [s] during 73.5% of errors). Substitution errors occurring when the target was an affricate usually involved both place and manner of production (/tʃ/→ [p,t,d,f,ʃ,dʒ,w] during 86.7% of errors). Substitutions for velar articulations depended upon whether the target was voiced or voiceless. 50% of target /g/ substitutions were characterized by errors in place of articulation (/g/ → [d]), and 37.5% of targets were devoiced. In contrast, errors of substitution for target /k/ were characterized by both place (/k/→ [p,t,d] = 77% of substitution errors), place and manner (/k/→ [tʃ,n, s] = 6.6% of substitution errors) and errors of voicing (/k/→ [g] = 18% of substitution errors). Phonemes which were considered the least vulnerable, /w,b,n/, involved changes in the manner of production and not place of articulation (/w/ → [b], /b/ → [p], /n/ → [d]). The results in Table 8-1 suggest that articulations involving the tongue are more frequently substituted than those involving the lips. We might propose that articulations involving lingual gestures require more complex motor programming than those which do not require precise lingual articulation. On the strength of the perceptual analysis we might speculate that lingual articulations are more erroneous following a CVA than bilabial which remain relatively preserved.

8.3.2 Substitution of fricative and affricate articulations

The relative difference in complexity of muscular activity for the production of different phonemes may be a plausible explanation as to why fricatives and affricates were more frequently substituted than other sounds. These phonemes require a delicate and controlled balance of protagonist and antagonist muscles to create the specific stricture for maintaining turbulent airflow. Hardcastle (1976) believes that these articulations involve more delicate neuromuscular control than stops. He states that production of fricatives requires "maximum delicacy both of muscular control and sensory feedback" (p.134). /ʃ/ was the most frequently substituted phoneme for all aphasic speakers (see Table 8-1). Out of 34 substitution errors perceived the following phonemes were produced instead: [s] (25/34); [z] (1/34); [tʃ] (6/34); and [t] (2/34) (see Table 5-8, Chapter 5). What is of interest is that the aphasics appear to maintain a similar motor control and the auditory quality of frication during substitutions of target /ʃ/. Whilst antagonist and protagonist muscles remain balanced when the post alveolar fricative is substituted by an alveolar fricative the precise neuromuscular control may be deficient because the latter is more anterior in the mouth and has a greater degree of constriction. This imprecision in articulation is possibly a result of inaccurate programming of the intrinsic transversus muscle, which acts in synergism with the posterior genioglossus in the forward-backward movement of the tongue tip/blade and the intrinsic verticalis and transversus muscles which are responsible for the degree of grooving (Hardcastle, 1976). Therefore whilst some of the delicate precision required for a fricative is maintained in these substitutions other aspects of muscular control are not.

Substitution errors for /tʃ/ were as follows: [ʃ] (8/15); [t] (2/15); [d, f, dʒ, p, w] each 1/15). The majority of substitutions involved replacing the affricate with a single phoneme and 53% (8/15) of these maintained the fricative portion of the affricate as opposed to the stop. This is perhaps surprising since the fricative requires the more complex neuromuscular control.

The majority of substitution errors for the fricatives /s/ and /z/ involved errors of voicing (5/7 = 71%). Once again the balance of protagonist and antagonist muscles was maintained.

8.3.3 Substitution of velar plosives

74% of voiceless velar plosives targeted by all the aphasic speakers were substituted by either /t/ (40/61) or /d/ (5/61), and 50% of voiced velar plosives were substituted by a voiced alveolar plosive and one target was substituted by /tʃ/ (see Table 5-8, Chapter 5). Therefore in total 72% ((40+5+4+1)/(61+8)) of velar targets were substituted by articulations involving the tongue tip and/or blade. Analysis of the substitution errors for the individual aphasia syndromes highlighted that velar plosives were more frequently substituted than alveolar plosives for all aphasic speaker groups (see Table 5-15, Table 5-16, Table 5-17, and Table 5-18, Chapter 5). These results are summarized in Table 8-2 for convenience.

It would appear from these results that plosive articulations involving the tongue body were more vulnerable to substitution than those involving the tongue tip/blade for all aphasic syndromes. Furthermore, for all of the aphasic subgroups except anomic aphasics, there is a strong tendency for the velar plosive to be replaced by an alveolar plosive when a substitution is detected through auditory analysis. The substitutions may reflect the frequency that the phoneme has in the language. Kent (1994) suggests that alveolar articulations are more common than velar articulations in English (alveolars: 46% vs. velars 9%). Perhaps there is a frequency effect in aphasic speech such that less frequently occurring phonemes are replaced by those that are more frequent. With reference to Dell's model of ISA we could suggest that alveolar phonemes have a higher resting level and therefore are selected in preference to velars due to a higher level of activation at the decision stage of phonological encoding following feedback and feedforward processes.

Alternatively, Sugishita et al. (1987), in their EPG analysis of the perceived omission errors of two apraxic speakers suggested that apraxic speakers are unable to inhibit tongue tip elevation. Perhaps this inability is not only a characteristic of AOS but a more general feature of the speech of aphasic speakers with the exception of anomic aphasics. This would explain the more frequent substitution of an alveolar for a velar plosive in preference to a velar for an alveolar plosive.

Aphasia syndrome	Percentage of substituted plosives		
	Alveolar	Velar	Velar substituted by alveolar plosive
Broca's with AOS	7.7%	34.4%	77.3% (17/22)
Broca's without AOS	9.3%	12.7%	64.3% (9/14)
conduction	7.5%	26.5%	95.5% (21/22)
anomic	1.6%	9.6%	18.2% (2/11)

Table 8-2: Table summarizing the percentage of substituted alveolar and velar plosives, and the percentage of velar plosives substituted by alveolar plosives for each aphasia syndrome detected through perceptual analysis.

8.4 Additional Information That The EPG Data Can Bring To An Auditory-Based Analysis

Analysis of the EPG data suggests that perceptual analysis alone is not sensitive to certain errors made during the speech signal. Through examination of the lingual/palatal contact patterns it becomes obvious that certain observations or presumptions made through perceptual analysis were either incorrect or at least only partially accurate. The EPG contact patterns for target singleton plosives where a substitution was detected through auditory analysis were examined (see Section 5.1.7). The EPG data revealed that of the twenty-eight perceived substitutions seven (25%) were not "pure" substitutions. During these productions lingual/palatal contact patterns did not confirm the auditory impression. Target WF velar plosives where a bilabial substitution had been detected (FM: "shark" 1 → [ʃaːɹp], "shark" 2 → [tʃaɹp]) showed additional alveolar lingual/palatal contacts typical of a stop gesture. This would suggest that the velar had not been substituted by a bilabial but that two stop gestures had been produced simultaneously in its place. A single bilabial was detected presumably because it was released after the alveolar MAG. A possible explanation for the production of two intrusive gestures will be offered in Section 8.4.4.

There was also evidence of EPG contacts during perceived substitutions of target alveolar and velar plosives. During these a double alveolar/velar articulation was identified through analysis of the EPG where a "pure" substitution had been detected auditorily. Therefore the target gesture and an intrusive gesture had been produced. A single phoneme was detected auditorily presumably because one of the stop gestures was released during the closure phase of the other. For example, a clear alveolar substitution was detected during the second repetition of "key" produced by IE ("key" → [tʰiː]). The sequence of EPG patterns for this target identified full velar closure prior to the alveolar gesture. The alveolar commenced prior to the release of the velar resulting in a period of double velar/alveolar articulation. The velar gesture was released during the alveolar closure which is presumably why a substitution and not the correct target phoneme was detected. The production of these double articulations are discussed in relation to Dell's model of ISA in Section 8.4.4.

It would seem that the production of a "pure" substitution is not as frequent in the data as an auditory-based analysis suggests. EPG contact patterns for the twenty-eight substitutions identified here confirmed the auditory-based impression during only 75% of productions. This has important implications for therapeutic intervention. A "pure" substitution assumes a linguistic deficit. However, the presence of the additional gestures suggests that these errors may also be due to faulty motor programming or faulty feedback. These issues will be discussed in Section 8.4.7 and Section 8.4.8.

8.4.1 Revised order of vulnerability following analysis of the EPG data

Auditory analysis suggested that Broca's aphasics with AOS demonstrate errors of substitution for all places of articulation. In contrast, Broca's without AOS, conduction and anomic aphasics produced bilabial plosives, labiodental fricatives and nasals which were never substituted by another phoneme. From the substitution errors identified through auditory-based analysis it was suggested that there was an order of vulnerability of phonemes to substitution across all aphasic speakers. It was proposed that articulations involving the tongue were more likely to be substituted than those involving the lips. However, examination of the EPG data revealed speech errors that the perceptual analysis failed to identify, in particular the presence of misplaced lingual/palatal contacts (MAGs). These MAGs are additional alveolar or velar lingual gestures which were identified through analysis of the EPG data at inappropriate places in the utterance. They are often undetected through auditory analysis (75% of occurrences) and have never been identified in normal speech. The MAGs were frequently observed during target bilabial plosives resulting in a double articulation and therefore cannot be classified as straight substitutions. Whilst the perceptual study suggested that bilabial plosives were not subjected to substitutions for all the aphasics except those diagnosed with AOS, the EPG data revealed abnormalities in their production. The number of MAGs and the percentage that an MAG occurred during the production of singleton phonemes (not clusters) in word lists A and B plus the repetition task was calculated for all subjects (see Table 8-3)[4].

	Most vulnerable →												→ Least vulnerable
Phoneme	/b/	/w/	/ʃ/	/h/	/g/	/m/	/s/	/f/	/k/	/z/	/p/	/tʃ/	/d/	/t,n,l,r/
Error incidence	14 9(A) 4(V) 1(D)	4 1(A) 2(V) 1(D)	13 12(A) 1(V)	2 2(A)	2 2(A)	1 1(A)	3 2(A) 1(V)	1 1(A)	16 16(A)	1 1(A)	1 1(A)	1 1(V)	2 2(V)	0
Total	76	38	158	38	40	20	80	40	657	60	87	78	247	246,80,60,160
%tage of error	18.4	10.5	8.2	5.3	5.0	5.0	3.75	2.5	2.4	1.7	1.5	1.3	0.8	0

Table 8-3: The actual incidence and percentage of MAGs during the production of single phonemes (e.g. not clusters) from word lists A and B and the repetition task for all aphasic speakers. The total row indicates the total number of possible occurrences of each individual phoneme as a singleton. The number of alveolar (A), velar (V), and double alveolar/velar (D) MAGs is shown for each phoneme.

What is immediately obvious is that MAGs were most frequently detected during voiced bilabial plosives (/b/) (18.4% error). Perceptual analysis indicated that this phoneme was one of the least vulnerable to substitution by aphasic speakers suggesting that only those diagnosed with Broca's aphasia with AOS demonstrated any difficulty with voiced bilabial plosives. There were a total of 14 MAGs noted during the production of target voiced bilabial plosives, only 6 of these were produced by speakers diagnosed as Broca's with AOS. If we ignore this subgroup there were still 8 MAGs noted for Broca's without AOS, conduction and anomic aphasics. Since there were 8 aphasics without AOS and 2 words in each word list A and B which contained voiced bilabial plosives (word list A: "book", "beak"; word list B: "bookshop", "box") these subjects produced MAGs on 12.5% of possible productions (8 MAGs / (4 words × 2 repetitions × 8 subjects).

Table 8-3 indicates that /w/ was the second most common phoneme for a MAG to be detected. Out of the 4 MAGs noted two were produced by a Broca's aphasic without AOS (CR). Therefore 6.25% of labial velar

[4]The total row, indicating the total number of possible occurrences for each phoneme is different to that shown in the error matrices (Table 5-19, Table 5-20, Table 5-21, Table 5-22, Table 5-23, Chapter 5). This is because unrecognizable and distorted productions were eliminated during the perceptual analysis of substitutions.

approximants produced by aphasics without AOS demonstrated MAGs (2 MAGs × 2 repetitions × 8 subjects).

Alveolar MAGs were far more common than velar or double alveolar/velar MAGs as can be seen from Table 8-3. Possible reasons for this are discussed in Section 8.4.3.

Whilst the perceptual analysis suggested that aphasics not diagnosed with AOS did not substitute bilabial articulations reflecting that these articulations are easier for this group of speakers, EPG analysis revealed information that did not appear to be available to the listener. Although these MAGs were undetected through auditory analysis the EPG patterns appeared as spatially normal alveolar (Figure 7-43, Chapter 7) or velar (Figure 7-38, Chapter 7) plosives and double alveolar/velar (Figure 7-33, Chapter 7) articulations. It is proposed that the reason why these MAGs were undetected through perceptual analysis of the data is because they were produced simultaneously with, but released prior to, the bilabial plosive (see Figure 7-33 and Figure 7-34, Chapter 7 for evidence of this).

8.4.2 MAGs detected through EPG data analysis during the production of target velar and alveolar plosives

The EPG data analysis which identified MAGs supported the results from analysis of substitutions in the study which investigated the relationship between phonetic transcriptions and EPG patterns (Chapter 4) because target velars were more frequently associated with MAGs than alveolars. The number of target alveolar and velar plosives (singletons) in word lists A and B and the repetition task plus the number of MAGs occurring on each phoneme are shown in Table 8-4.

	Number of MAGs noted during target alveolar plosives	Number of MAGs noted during target velar plosives
Broca's with AOS	0	7
Broca's without AOS	1	3
conduction aphasic	1	8
anomic	1	0
Total number of MAGs (all aphasics)	3	18
Number of target singletons	493	697
%tage of targets showing MAGs	0.6%	2.6%

Table 8-4: Table showing the number of MAGs occurring during target alveolar and velar plosives, and the percentage of target alveolars and velars in word lists A and B and the repetition task where MAGs were identified.

Alveolar and velar MAGs detected during target velar and alveolar plosives respectively were spatially normal productions for each aphasic speaker except PW (conduction aphasic). The velar plosives were more vulnerable to the production of MAGs. These findings support the earlier claim that it is not solely those diagnosed with AOS following a CVA who produce errors involving the tongue tip/blade, but also Broca's without AOS and conduction aphasics. Similar to the perceptual findings the anomic speakers do not appear to make these errors. The occurrence of the alveolar MAGs during velar plosive targets could be a result of an inability to inhibit tongue tip activity which was suggested by Sugishita et al. (1987) for apraxic speakers.

What is striking from Table 8-4 is the relative infrequency of MAGs in the aphasic speech. However, two points should perhaps be made to justify the importance of their analysis. Firstly, these gestures were never produced by the control group nor have they been identified in earlier EPG studies of normal speakers. Therefore they are unique to neurogenic disorders and important in the development of models of speech production. Secondly, if lingual/palatal MAGs occur then it is not unreasonable to suggest that MAGs involving other articulators, for example the lips, may be a characteristic of aphasic speech.

8.4.3 Frequency of MAGs

Analysis of the EPG data revealed that alveolar MAGs were over three times more common than velar MAGs (57 alveolar MAGs compared to 18 velar MAGs). The incidence of MAGs did not appear to be related to the aphasia syndrome but instead subject specific. An absence of MAGs was noted for one Broca's aphasic without AOS (JM) and one anomic aphasic (HJ). As a group the anomic aphasics produced the fewest number of MAGs. Therefore all groups of aphasic speakers produce MAGs. Hardcastle and Edwards (1992) proposed that velar MAGs could be a characteristic of apraxic speech. Whilst this may be true the results of this study suggest that it cannot be regarded as a feature which enables differential diagnosis between AOS and phonemic paraphasia. Since all aphasic speakers were capable of MAGs and these did not seem to differ in their appearance between aphasic groups, the origins of the MAGs are presumably similar.

Hardcastle and Edwards did not identify any alveolar MAGs in the speech of the four apraxic speakers. In this study 100% of FM's (Broca's with AOS) MAGs were velar compared to MU (Broca's with AOS) whose velar MAGs only constituted 10% of occurrences. For this speaker there was a preponderance of alveolar MAGs. MU produced 36 out of the 57 noted by all aphasic speakers. Hardcastle and Edwards (1992) studied subjects who were diagnosed as apraxia with no aphasic involvement. However, it is unlikely that the presence of aphasia concomitant with the apraxia could account for the identification of the alveolar MAGs in the present study. This is because Sugishita et al. (1987), who also studied purely apraxic speakers, noted the presence of alveolar MAGs during perceived omission errors. The results of the current investigation indicates that the production of MAGs following a CVA are not restricted to subjects with AOS and cannot confidently be related to one of the traditional aphasic syndromes. Instead the frequency and type of MAG appears to be specific to an individual and must be related to other factors. This may include location of the brain lesion.

Whether a MAG was related to other phonemes in the word was different for alveolar and velar MAGs. 72% of velar MAGs occurred during words where a target velar was present. In contrast, only 30% of alveolar MAGs occurred in words where there was an alveolar plosive or nasal. This may have important implications for models of speech production. We might propose that the velar MAGs are a result of faulty sequencing and timing. This explanation is not appropriate for alveolar MAGs since 70% occurred in words where there was no target alveolar stop. They may result from a higher level impairment, for example phoneme selection (see Section 2.6.2.16), or as Sugishita et al. (1987) suggest due to an inability to inhibit tongue tip elevation.

8.4.4 Can Dell's model of ISA explain the production of substitutions and MAGs?

Hardcastle and Edwards (1992) proposed that "misdirection ...... can be viewed as evidence of loss or interference with the speakers' ability to achieve the correct articulatory posture for a speech sound" (p.325). They go on to say that this could be a problem with selection or motor mismanagement. Sugishita et al. (1987) preferred an explanation in terms of motor control, suggesting that the apraxic speaker has "difficulty in preventing the tip of the tongue from rising up to the alveolar or postalveolar region" (p.1412) which they propose indicates a problem with "inhibition of tongue activity" (p.1412).

Martin et al. (1994) suggested that the origins of paraphasia in deep dysphasia could be explained within a model of spreading activation. As it stands, Dell's model of ISA cannot explain the presence of MAGs in the speech of the aphasic speakers for several reasons discussed below. However, with certain modifications could the model explain the production of substitutions and MAGs?

Let us first consider the "pure" substitutions that were identified (5.1.7, Chapter 5). Nineteen of the twenty-one "pure" substitutions involved the substitution of an alveolar plosive for a target velar plosive (/k/→ [t] 17/21 "pure" substitutions; /g/ → [d] 2/12 "pure" substitutions). In Kent's (1994) listing of phoneme rank order of occurrence, /k/ is ranked eighth compared to /t/ which is ranked second. The voiced cognates /g/ and /d/ are ranked seventeenth and sixth respectively. We might suggest that the resting levels for the alveolar plosives and velar plosives are not the same but that the alveolar articulations have higher values due to the increased occurrence in the English language. Therefore during spreading activation these phonemes are incorrectly chosen at the decision stage because they reach a higher level of activation.

The remaining two "pure" substitutions occurred during production of the target word "tick" which was heard as [kʰɪt] (produced by IE, conduction aphasic). Whilst the alveolar and the velar have both been substituted it may be more reasonable to suggest that this is due to faulty sequencing of the phonemes (metathesis). This error cannot be explained by Dell's model as it stands due to the syllable position constraint. However, the elimination of this is a suggestion that Dell has himself proposed (Dell, 1986) and one which is discussed in more detail below.

It would appear that Dell's model can account for the occurrence of "pure" substitutions (and metathesis if the model is modified). How well does it explain the production of MAGs, for example, the articulation of a velar MAG during production of a target bilabial which was detected during production of the word "book"? Velar MAGs during bilabial plosives in word initial position were noted in the speech of six aphasics (FM, MU, BA, CR, IE, FC). According to Dell's model, following current node status being assigned to the intended morpheme ("book") its activation level is incremented by an arbitrary amount which Dell suggests is 100 units. This morpheme node then sends a fraction of its activation to all nodes directly related to it. Since data from the single words was used to identify the MAGs, competing morphemes which may have caused interference during phonological encoding can be easily identified. In the case of a single syllable word such as "book" there are no such morphemes. Therefore spreading activation from the morpheme to the phoneme level should activate only a /b/ onset. Since there are no upcoming morphemes there can be no anticipatory activation. A diagram to show the spread of activation is shown in Figure 8-1. With the model of ISA as it stands there appears to be no explanation for a velar MAG in onset position. However, by modifying the model to eliminate the position encoding restraint it may be possible to explain the velar MAG in word initial position. The MAG could then be accounted for by suggesting that it is an anticipatory error. However, this modification is not sufficient on its own to account for the MAG. The problem now is to explain the simultaneous articulation of two phonemes as opposed to a single phoneme. In Dell's model of ISA a single phoneme node with the highest level of activation is tagged and consequently selected at the decision stage. One explanation would be to suggest that in these examples where velar MAGs are detected, two phonemes, a bilabial plosive and a velar articulation, share the same level of activation. This is not a feature of the original model proposed by Dell since the positive feedback continually revises the levels of activation until a point when one phoneme is higher than the others and a decision can be made. If the feedback was impaired such that the two competing phonemes could not be separated then maybe after a certain number of time steps both phonemes are selected. If this was true we might expect there to be a delay in the decision making procedure due to the repetitive feedback and feedforward operations which would be occurring in an attempt to activate one phoneme node more than another. Analysis of the acoustic EPG trace reveals that there was often an apparently long pause between production of the indefinite article "a" and the target word when MAGs were detected (see Figure 7-23, Chapter 7). An alternative explanation for the simultaneous occurrence of two phonemes, the target and a MAG, would be to suggest that following a CVA the decision stage in the model is impaired in some way such that more than one phoneme is tagged and consequently selected. The elimination of the position encoding restraint would still be necessary in this example to explain the interference from a velar articulation.

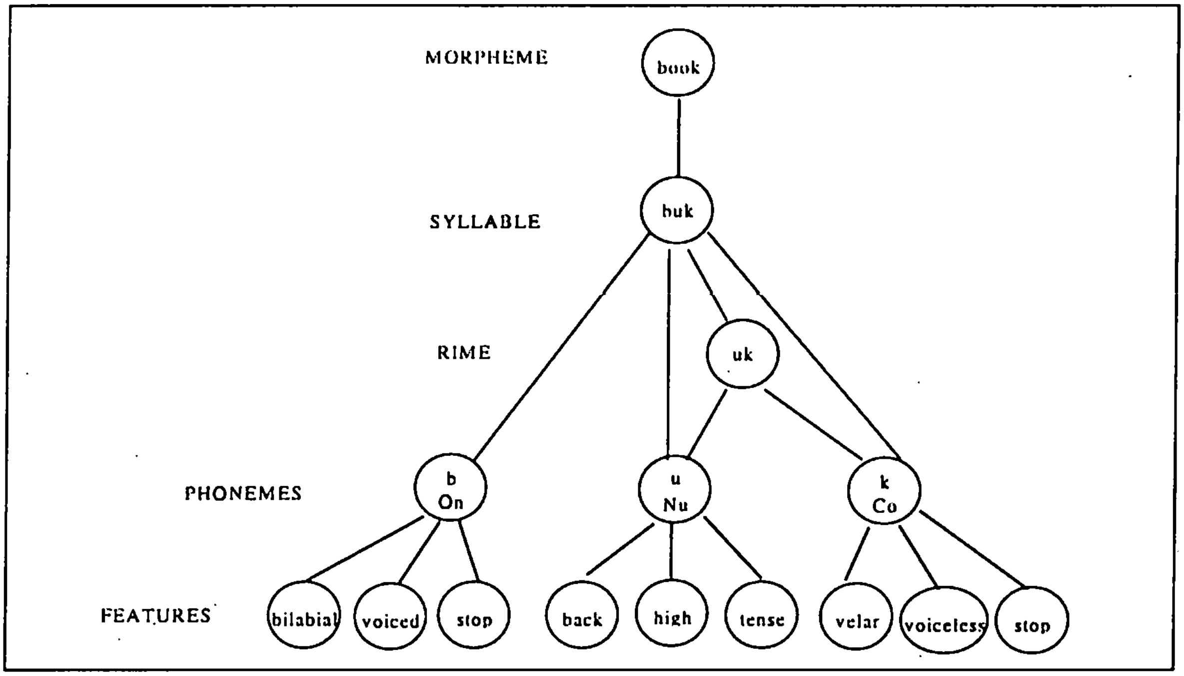


Figure 8-1: Phonological encoding for the word "book" as predicted by Dell's model of ISA. (On)set, (Nu)clei, and (Co)da are labeled. All connections are top-down and bottom-up.

One might suggest that elimination of the syllable position constraint is not necessary to explain the presence of MAGs in words containing more than one morpheme. For example if an alveolar MAG was observed during production of the word initial velar in "cocktail" we would predict, according to Dell's model of ISA, that the interference had originated from the alveolar onset in the second morpheme ("tail"). However, if an alveolar MAG was observed during production of the word "kitkat" the MAG would have no source because both target alveolars occur in coda position. Therefore the modification proposed above regarding elimination of syllable position constraint is still necessary. Without modification the alveolar coda in each morpheme cannot affect the velar onset. Phonological encoding for the word "kitkat" within this modified ISA model which does not assume syllable position constraint is shown in Figure 8-2.

The modified model of ISA can now begin to explain the WI alveolar MAGs occurring simultaneously with the target velar plosive in disyllabic words where there is both target alveolar and velar articulations in the word (e.g. "kitkat" or "cocktail"). There is still the problem of two phonemes occurring simultaneously in WI position. The explanations proposed for this phenomenon are the same as those given for "book" (see above).

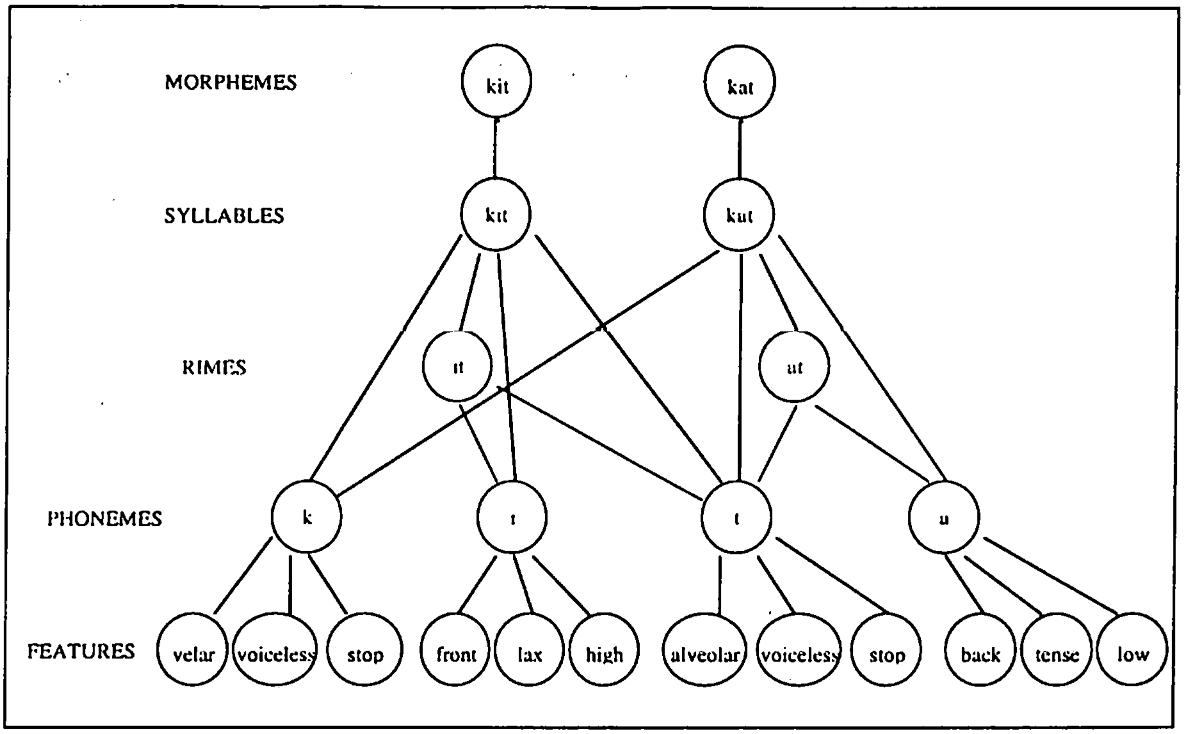


Figure 8-2: Phonological encoding for the word "kitkat" in a modified version of Dell's ISA model of speech production. Notice that position encoding at the phoneme level has been eliminated. All connections are top-down and bottom-up.

8.4.5 MAGs not explained by Dell's model of ISA

The proposed modifications to Dell's ISA model made in this section cannot explain the presence of all the MAGs which were identified through analysis of the EPG data. For example, if we consider the presence of an alveolar MAG during production of the target word "book" (e.g. PW, conduction aphasic). Even with the elimination of the position encoding constraint it would seem impossible to account for the alveolar lingual palatal contacts. This is because there is no target alveolar articulation in the morpheme requiring phonological encoding and no upcoming morphemes. The word prior to "book" in the word list ("gear") did not have a target alveolar and the subject did not see the following target word until the current word was successfully recorded onto EPG. Therefore there would have been no interference from preceding or following morphemes in the word lists so there is no source for the interference as there was for the velar MAG. We could propose further changes to Dell's model of ISA in an attempt to account for the alveolar MAG which would also be capable of explaining the velar and double alveolar/velar MAGs that were noted in the data. For example, following activation of the current morpheme, activation then spreads to all phonemes which share the same manner of articulation. When phonologically encoding the word "book" the phonemes /b,p,d,t,g,k/ would all be initially activated for the onset position (and also coda position). The position constraint could remain in place since all plosives would be activated. Following this feedback and feedforward mechanisms would follow the same principles as those outlined by Dell (1980, 1985, 1986, 1990). However, this is not sufficient to explain the MAGs since the ISA theory predicts that the phoneme with the greatest resulting activation level will be selected. Therefore we must find a way of explaining how more than one phoneme can be selected. Two suggestions were made in Section 8.4.4. Firstly, perhaps one phoneme never acquires greater activation than all the rest but instead more than one phoneme share the highest activation level. The resulting situation is one of stalemate. After a certain time period all those sharing the highest level of activation are selected causing simultaneous production within the confines of motoric ability. Alternatively, the decision stage is disrupted following a CVA such that more than one phoneme can be encoded for production and it is unspecified as to the number which can result.

These explanations for the presence of MAGs not only require modification to the model outlined in Section 2.6.2, Chapter 2 but they also assume that following a CVA parts of the process for phonological encoding are damaged. Even if these changes are possible, they still do not adequately account for all the MAGs that were noted in the aphasic speech. For example, during production of the word "racer" a velar MAG, typical of a plosive articulation, was produced by one Broca's aphasic without AOS (CR) (see Figure 7-22, Chapter 7) simultaneously with the WI alveolar approximant (/r/) (there was also a post alveolar fricative detected on auditory analysis prior to the alveolar approximant). The modifications proposed in this section cannot explain the positioning of this MAG. Since there are no plosive targets in the word the modified model predicts that this group of phonemes would not be activated.

8.4.6 Summary

Dell's model of ISA (1980, 1985, 1986, 1990) is unable to fully explain the presence of MAGs in the speech of the aphasic subjects in its current form. Various modifications to the standard model would be necessary to account for their production. Therefore it would appear that Dell's model of activation is not able to account for certain features of aphasic speech which have been identified in this study and in the study of apraxic speakers (Hardcastle and Edwards, 1992; Sugishita et al. 1987).

8.4.7 Is there more than one type of MAG?

Whilst MAGs have been detected in the speech of the aphasic subjects they have, up to now, been considered a single error type. However, the data suggests that there may be more than one kind of MAG which relate to different underlying deficits in speech production. We might want to separate those MAGs which occur when there is a target plosive and involve the tongue tip/blade from those involving the body of the tongue. Another category would be for double alveolar/velar MAGs which involve both components. The alveolar MAGs could be explained in several ways: an inability to suppress tongue tip elevation (Sugishita et al., 1987); an error in sequencing and timing (if there was a target alveolar in the word); or a result of incorrect phoneme selection. The latter may be related to Dell's model of ISA by suggesting that the increased frequency of alveolars compared to velars in the English language (Kent 1994) increases their resting activation level causing them to be incorrectly selected during phonological encoding. Since velar MAGs occurred most frequently when there was a target velar in the word they may be due to incorrect sequencing in the programming of the articulators. However, this does not explain the presence of all velar MAGs. Further explanations are required. It may be fruitful to consider the surrounding vowel context. For example, are velar MAGs more frequent when they precede a back vowel? This was not controlled for in this thesis but would be an interesting area for further investigation.

Whether the errors occurring on target fricatives are really MAGs or errors of distortion was raised in Section 7.8.1, Chapter 7. It is tempting to classify these errors as overshoots of the target similar to those identified by Hardcastle et al. (1985) in the speech of a dysarthric subject (see p.256). If they are overshoots then these errors should be classified as distortions of the target which Hardcastle et al. (1985) proposed was a result of "inadequate control over muscular tension requirements" (p.266). Therefore Hardcastle et al. (1985) are suggesting a disruption at the level of motor programming and not a linguistic based error.

However, what if the errors which have previously been described as distortions are really MAGs? An alveolar MAG occurring simultaneously with a post alveolar fricative, for example in "shark" (see Figure 7-26, Chapter 7) would have to be realized as an alveolar plosive because it is physically impossible to produced an alveolar fricative and an alveolar plosive simultaneously since both gestures use the tongue tip and blade. Therefore if both phonemes were selected, as was suggested earlier in discussing MAGs in relation to phonological encoding within a model of ISA, their simultaneous articulation would not be seen. This is not to say that only one phoneme has been selected. Subsequently the question as to whether these errors are distortions or MAGs remains unsolved. We might want to limit our definition of an MAG to those misdirected gestures involving a different articulator than the target. This would mean that alveolar MAGs which were detected during target alveolar or post alveolar fricatives are not MAGs.

8.4.8 Feedback

During the repetition task, one aphasic, MU (Broca's with AOS) produced an alveolar MAG prior to the correct velar target during eight out of twelve productions of "clock" and six out of twelve productions of "kitkat". Both words include target phonemes involving the tongue tip/blade. We might suggest that an error in sequencing, perhaps as a result of a lesion at some point along the motor loop (Kent, 1990), is detected by sensory feedback, the MAG aborted and the target gesture articulated. Edelman (1989) suggests that the basal ganglia are involved in aspects of motor programming and sensorimotor coordination and the cerebellum is responsible for the control of timing and synchronization of movements. Therefore we may suspect that MU has a lesion within the cerebellum. Unfortunately, the CT scan for this subject was not available.

Conversely, IE (conduction aphasic) produced the correct velar target prior to the alveolar MAG and it was the MAG that was consistently detected through auditory analysis (see Appendix A). For this subject it would appear that there is impaired feedback since following the articulation of the correct phoneme an incorrect one is articulated and phonated. This appears distinct from the previous example where the feedback identified the error which could then be corrected.

For MU we might suggest another type of MAG, a triggering MAG, since the target velar appears to be triggered by the production of an alveolar MAG. Evidence for this comes from continuity of timing between the two gestures. Likewise, the target gesture and the alveolar MAG produced by IE appear to be a coordinated structure. This structure could be explained with reference to Dell's model of ISA by suggesting that the two phonemes acquire equal levels of activation but the alveolar MAG is produced marginally later and therefore detected through auditory analysis.

Since the majority of MAGs were undetected through auditory analysis (75%) a detailed analysis of the MAGs might give an indication as to whether different types of feedback are operating efficiently, for example auditory, tactile or proprioceptive.

8.4.9 Summary

It would appear that there may be more than one type of MAG which can be accounted for at different levels of processing. These explanations are related to the articulator involved (tongue tip/blade versus tongue body), whether the MAG is a target gesture, and the sequencing of the MAG with other target gestures in the word.

8.5 Sequencing And Timing Of Two Independent Lingual Gestures

Hardcastle (1976) suggested that the tongue could be viewed as an organ which has at least two independently controllable components, the tip/blade and the more posterior main body of the tongue with different muscle groups responsible for the innervation and movement of the two parts. Farnetani (1997) states "the tongue tip/blade can act quasi-independently as two distinct articulators" (p.371). Recent EPG studies have revealed the presence of temporal overlap of gestures during continuous speech of these two components in normal speakers (Hardcastle, 1985; Butcher, 1989; Ingram and Hardcastle, 1990; Gibbon, Hardcastle and Nicolaidis, 1993; Byrd, 1994) and the degree of overlap has been investigated in several languages (Gibbon et al. 1993). The amount of overlap that has been recorded has varied between studies probably as a result of methodological differences in annotating data. For example, Hardcastle (1985), in his study of /kl/ clusters, marked the first indication of tongue movement towards the alveolar /l/ position from the EPG trace. Gibbon et al. (1993), in their investigation of the same sequence, took the first frame with any of the four mid-sagittal electrodes contacted in the first four rows as an indication of approach to lateral closure. This point would occur later in the sequence than that chosen by Hardcastle (1985). Despite the differences in segmentation both studies revealed temporal overlap in the speech of normal subjects although this was unsurprisingly less in the study by Gibbon et al. (1993).

Whilst most investigations have been interested in anticipatory coarticulation in normal speakers, Ingram and Hardcastle (1990) studied the magnitude and direction of coarticulation in the speech of one apraxic subject. The two main findings were that the apraxic speaker tended to avoid temporal overlap and that there were abnormally long latencies between the release of the first lingual gesture and the movement of the tongue body towards the second. These results were supported by Hardcastle and Edwards (1992).

The present study looked in detail at two sequences involving the different components of the tongue to observe the coarticulatory effects of nine aphasic speakers compared to ten control subjects. The first was the /kl/ sequence at the beginning of the word "clock" and the second was the /tk/ sequence crossing the morpheme boundary in the word "kitkat". Each word was repeated ten times and the results summarized in Chapter 6 and Graph 6-3 to Graph 6-40 inclusive The two sequences could in theory elicit different coarticulatory effects. Anticipatory coarticulation (gestural overlap) may be evident in both /kl/ and /tk/ sequences. In the /tk/ sequence we may also evidence assimilation, "the process by which one or both of two successive segments become more like the other" (Catford, 1977: p.225). We would expect the alveolar to assimilate to the same place of articulation as the velar such that no lingual/palatal contacts in the alveolar region would be seen on the EPG trace. Whilst the debate continues as to whether coarticulation and assimilation are two distinct processes or alternatively two phenomena that fall on different parts of a continuum (Holst and Nolan, 1995), this distinction is not the primary concern here. Instead this section has two aims: to highlight any differences in the sequencing and timing of two relatively independent lingual gestures produced by aphasic and normal speakers; to try and explain the patterns emerging in relation to Articulatory Phonology (Browman and Goldstein, 1990), Dell's model of ISA (1986) and Kent's model of speech production (1990).

8.5.1 Coarticulation during the /kl/ sequence in "clock"

Hardcastle (1985) identified four sequencing pattern types produced by four normal speakers during the production of /kl/ sequences (see Table 3-6, Chapter 3) which he suggested could be associated with different phonetic and syntactic environments, for example, syllable or major syntactic boundaries. In initial clusters he found that the approach to the /l/ typically occurred during the /k/ closure period thus indicating temporal overlap of the two gestures. This was not the most frequent pattern used by either the control speakers or the aphasic speakers in this study. Similarly, Gibbon et al. (1993) found that on average there was no overlap in their English speaking subjects during /VklV/ sequences. The results of the present study and that of Gibbon et al. (1993) may be a direct result of differing annotation points. The approach to /l/ closure in this investigation was taken as the first frame showing contact in rows 1 or 2 except when the articulation was felt to be retracted when contact in row 3 was accepted as the approach. The annotation point occurred much later in the data from this investigation (and Gibbon et al., 1993) than Hardcastle's (1985) study and therefore the differences in the most frequent sequencing pattern are unsurprising. The point chosen by Hardcastle to indicate tongue movement towards the alveolar position from the EPG trace was felt to be vague and underspecified. Since the question of motor control following a CVA is prevalent in the literature a specific point within the alveolar region was chosen. It was felt that this was a more reliable indicator of movement towards the /l/ articulation.

The release of the velar articulation prior to the onset of tongue tip/blade contact for /l/ (a type 1 pattern) was noted during 46.7% of aphasic speakers productions compared to 61% of the normal speakers and was the most common pattern favoured by all subjects. However, it is recognized that tip/blade movement can be observed prior to contact being seen on the EPG trace. Examples of temporal overlap between the /k/ and /l/. contact patterns were noted particularly in the control group (39%) compared to 16% of the aphasic productions.

8.5.2 Coarticulation during the /tk/ sequence in "kitkat"

Coarticulation was more frequent in the normal speakers compared to the aphasic speakers when the lingual gestures were separated by a morpheme boundary. This was evident through the percentage of type 2 (full velar closure in WM position prior to the release of the WM alveolar stop) and type 3 (assimilation of the alveolar to the velar place of articulation) sequencing patterns. 34% of type 2 and 47% of type 3 sequencing pattern were recorded for normal speakers compared to 16.7% and 8.9% respectively for the aphasic group. The small percentage of assimilated sequences for the aphasic group is surprising since this is a dialectal feature of Scottish, the glottal stop being a frequent realization of /t/ (Hughes and Trudgill, 1979). All the aphasic speakers were Scottish compared to only two of the control group (7 were from regions of Southern England and one was Australian).

8.5.3 Incidence of coarticulation in aphasic speech

It would appear from the limited set of data in this study that aphasic speakers as a group have a specific problem with coarticulation. In particular they less frequently anticipate upcoming gestures and rarely assimilate two adjacent phonemes to a single place of articulation. Farnetani (1997) proposes that coarticulation is an economical way of speaking. Therefore it seems that aphasic speakers as a group lose the ability to be economical in speech. However, there appeared to be differences between the aphasic subgroups. Ingram and Hardcastle (1990) suggested that apraxic speakers avoid temporal overlap a view that could not be supported by the results of this investigation. Of the two AOS subjects in this study, FM (Broca's aphasic with AOS) produced six repetitions where temporal overlap was evident during production of the target "clock". In two of the remaining four repetitions the approach to the /l/ commenced prior to and was released after the velar closure. This type of gestural overlap was also seen in the speech of the normal speakers investigated by Hardcastle (1985) although it was rare and only occurred at major syntactic boundaries. FM also produced assimilated /tk/ sequences during the production of "kitkat" during three repetitions. MU, also classified as a Broca's aphasic with AOS, failed to produce the two target gestures for all repetitions of "clock". Following the velar closure either a MAG, typical of an alveolar plosive and not an alveolar lateral approximant, was noted (7/10 repetitions) or there was no second gesture before the vowel. Assimilation was noticed during a single repetition of "kitkat" for this subject. Therefore the results from the /kl/ and /tk/ data in this study do not support the view of Ingram and Hardcastle (1990) that apraxic speakers avoid temporal overlap. For FM coarticulation is frequently evident.

8.5.4 Latencies between two lingual gestures

Hardcastle (1985) noted that the temporal delay between the release of the /k/ and the onset of the /l/ in word initial position was a maximum of 30 msecs. Analysis of the data from this study revealed that the same distance was a maximum of 80 msecs for control subjects and 90 msecs for the aphasic speakers. The greater values are likely to be a result of annotation differences between the two studies discussed in Section 8.5. The results from this investigation would suggest that there is little difference between the two groups of speakers during production of /kl/ sequences.

Ingram and Hardcastle (1990) noted that their apraxic subject demonstrated abnormally long latencies between the release of a velar stop gesture and the onset of an alveolar gesture in word medial position crossing a morpheme boundary. The latency between gestures noted in WI position in this study did not exceed 20 msecs for control speakers. However, it should be noted that sequences were alveolar/velar in this investigation (/tk/) and velar/alveolar in Ingram and Hardcastle's study. Byrd (1994) states that a "tongue tip consonant is more overlapped by a following tongue body consonant than a tongue body consonant is by a following tongue tip consonant" (p.160). If assimilation is regarded as the same as gestural overlap then the results from the control speakers support this statement since 47% of productions were assimilated, that is the alveolar place of articulation moved to the velar. In contrast, several of the aphasic speakers showed an increased delay period. Both conduction aphasics demonstrated a consistent increase (IE 110 to 200 msecs; PW 0 to 80 msecs), one anomic aphasic (HJ) produced longer latencies (110 to 260 msecs) whereas the other two produced values closer to the control speakers (FC 0 to 60 msecs; HL 10 to 50 msecs). The four Broca's aphasics only released the velar prior to the onset of the alveolar movement on three out of a total of forty repetitions and therefore cannot be compared to the control speakers.

It appears that the aphasic group showed increased durations between gestures within words across a morpheme boundary compared to the control group but not when the sequence was a word initial cluster. Since the Broca's aphasics with AOS only produced two such sequencing patterns for "kitkat" the data cannot confirm or deny the claims made by Ingram and Hardcastle (1990) regarding increased latencies.

8.5.5 Sequencing error patterns identified in aphasic speech

The sequencing patterns for normal /kl/ production previously identified by Hardcastle (1985) were not sufficient to describe the patterns exhibited by the aphasic speakers. Additional patterns were necessary to reflect errors of sequencing noted in the speech of the aphasics. In addition to the four pattern types noted by Hardcastle, three additional patterns were identified: omission of a phoneme; reversal of the ordering of phonemes; the presence of a MAG. The aphasic speakers also produced a greater variety of sequencing patterns than the controls during articulation of /tk/ in "kitkat".

Sequencing errors were noted during the production of /kl/ 37.7% of the time and of these 34.4% were errors of omission. In contrast, only 19.9% of target /tk/ sequences showed errors in the ordering of the phonemes (14.4% omission of /k/). From this we might predict that sequencing across morpheme boundaries is easier for aphasic speakers than a cluster in WI position. Darley (1982) in describing AOS noted that initial consonants were more often in error than consonants in other positions and that consonant clusters elicited more errors than singleton consonants or vowels because they were presumed to be more complex.

One subject, JM, a Broca's aphasic without AOS, consistently omitted the velar articulation during the /tk/ sequence in "kitkat". Farnetani (1997) defines assimilation as "contextual variability of speech sounds by which one or more of their phonetic properties are modified and become similar to those of the adjacent segments" (p.376). Therefore we might argue that JM is assimilating the /k/ to the alveolar place of articulation. However, since this pattern was not evident in any of the productions from the control speakers and the assimilation of the first consonant (C1) in a sequence to the second (C2) is almost universally preferred to that of C2 to C1 (Ohala, 1990), it is more likely that the sequencing pattern noted in the speech of JM is an omission error.

Errors in this investigation were characterized by omission of a phoneme or reversal of the normal order of sequencing. The former was more prevalent than the latter. Therefore it would appear that the aphasics use omission of an element as a method of simplification in preference to assimilation. In "clock" the /l/ was the phoneme most frequently omitted and the velar articulation retained. This may be a result of the complex nature of the alveolar lateral which requires more delicate neuromuscular control than a velar plosive. Alternatively, the ordering of the phonemes in the sequence may determine the order of vulnerability for omission. Additional and alternative sequences involving the tongue tip/blade and tongue body need to be analysed to test this proposal.

With the exception of a single omission produced by FC (anomic) during production of "clock" all errors of omission and reversal of phonemes were produced by those aphasic speakers diagnosed with Broca's aphasia both with and without AOS. This suggests that these subjects have the greatest difficulty ordering the two lingual phonemes. Conduction and anomic aphasics produced sequences which were typical of the control speakers. They appeared not to have any specific difficulty with the spatial sequencing of the tongue tip/blade and the tongue body.

8.5.6 Can Dell's model of ISA explain errors of omission?

Omission of the second element of the /kl/ cluster in word initial position could be explained by suggesting that the spreading activation appears to bypass the cluster node. It must still be present in the network structure to allow for intra-subject variability. If this node was circumvented then the model would only allow for a single phoneme node in word initial position. Since the omission usually involved the /l/ we might suggest that the resting level for the /k/ is greater than for the /l/ and therefore the velar is selected in preference to the /l/.

The omission error in word medial position cannot be explained in the same way since the two phonemes belong to two different morphemes and therefore, according to Dell, coded separately. Dell would presumably propose that a null element has been selected in preference to the onset /k/ which has resulted in the omission of a phoneme. However, this seems surprising if we consider that the onset node for the first morpheme is also a /k/. We might predict that this node's level of activation will be higher than the null element since it may not have returned to zero during the post decision clean-up stage. Lexical bias cannot explain the production of [at] in preference to [kat] during the encoding of the second morpheme since both are real words. However, Dell (1986) did propose modifications to his basic ISA model to account for the fact that sound errors affect content words more often than function words (Garrett, 1975). Dell suggested that the function words should have a resting level greater than zero and higher than the content words. If this is true then this may explain the production of [at] in preference to [kat].

Alternatively we might propose that the word medial sequence is not reduced to a single phoneme but instead there are two identical phonemes encoded but the first is unreleased. If this is true then the phonetic transcription for the word would be [kɪt˺tat]. This was seen in the speech of JM (Appendix A, Table A-29) although the syllable initial within word /t/ is sometimes substituted by a nasal or voiced alveolar plosive. If, as proposed earlier, the syllable position constraint was eliminated then the selection of a /t/ in preference to a /k/ could be accounted for by suggesting that the former had a higher resting level since it had not yet completely decayed.

8.5.7 Sequencing errors in relation to a neural model of speech production

Abnormalities that were noted in the speech of the aphasics included the omission of phonemes, reversal of two independent gestures and increased latencies between correctly sequenced phonemes. Whilst these were not consistent in the speech of all aphasics they do occur and therefore must be explained. Can these phenomena be related to the neural model of speech production proposed by Kent (1990) which was outlined in Section 2.6.1, Chapter 2?

8.5.7.1 Omissions

It is still unclear as to whether errors of omission are a result of faulty phonological encoding or at a lower level of speech production. Attempts to relate them to phonological encoding within Dell's model of ISA were made in Section 8.5.6. If however they are at the level of motor programming, we might predict that problems are associated with the preparation of sensorimotor trajectories. Kent et al. (1988) suggest that the basal ganglia is the structure responsible for this. MU (Broca's aphasic with AOS), CR, and JM (both Broca's aphasics without AOS) frequently omitted a phoneme from a consonant sequence. Both CR and JM are known to have damage involving the basal ganglia (see Figure A-4 plate 5 and Figure A-6, Appendix A for brain scans) which would support the views of Kent et al. (1988).

8.5.7.2 Reversal of gestures and increased latencies between correctly sequenced phonemes

Since the reversal of two gestures necessitates that the individual speech movements have been programmed it is the sequencing of these which is at fault. Kent (1990) in discussing conduction aphasia, which he states is primarily a disorder of phonetic sequence management, suggests that these difficulties are a result of a cortical lesion affecting the supramarginal postcentral gyrus or the arcuate fasciculus (a bundle of fibers transferring information between Broca's and Wernicke's area). MU and CR demonstrated occasional reversal of phonemes. Neither of these two speakers were considered to be conduction aphasics. Both were diagnosed with Broca's aphasia, MU with associated AOS. The supramarginal postcentral gyrus and arcuate fasciculus do not lend themselves to clear imaging on CT scans (Pentland, 1997). Therefore it is impossible to say whether these areas are damaged from CR's CT scan (Figure 4, Appendix A). An MRI would provide better information on these structures.

Presumably increased latencies between the two gestures could also be explained by predicting difficulties with phonetic sequencing management. Unsurprisingly this was a consistent feature in the speech of the two conduction aphasics (IE and PW). HJ (anomic aphasic) also demonstrated abnormally long latencies between alveolar and velar gestures in /tk/ sequences. Therefore it would appear that it was not just those subjects diagnosed as conduction aphasics who had difficulties in sequencing of gestures. Edelman (1989) has proposed that the cerebellum is the structure responsible for the control of timing and the synchronization of movement. Therefore we might propose that the timing difficulties experienced by MU, CR, IE, PW and HJ are a result of a disruption in the connection between the cerebellum and the motor cortex. An MRI better identifies the cerebellum than a CT scan. Unfortunately the CT scans in Appendix A do not provide this information.

8.6 Variability

8.6.1 What constitutes normal variability?

Before deciding whether neurologically impaired speakers are more variable than normal speakers we must first understand what constitutes normal variability. Several studies have suggested that speakers with AOS demonstrate greater variability than non-neurologically impaired speakers. But these decisions have often resulted from comparisons with a single control subject (Itoh and Sasanuma, 1984). There have been no studies investigating the inter- and intra-subject variability of normal speakers using EPG. Therefore this section of the investigation had two objectives: to assess normal variability; to compare the aphasic speakers with the control speakers to decide whether their articulations were more variable. Analysis of the EPG data revealed the degree of temporal and spatial variability produced by these two groups of speakers.

8.6.2 Temporal variability

8.6.2.1 Duration of stop closures

The duration of word initial closure in "deer" as measured by the EPG showed increased values for five of the aphasic speakers (FM, MU, CR, FC and HJ) (Graph 6-1, Chapter 6) and for "kitkat" all aphasic speakers except JM produced longer closure phases (Graph 6-2, Chapter 6). Since the rate of speech was not measured it was not possible to assess whether increased duration was a result of a slower speech rate in the aphasics. A measure of variability was made to assess whether there were any differences in the WI closure phases for these two words. Four out of the nine aphasics (MU, CR, FC and HJ) showed increased variability in duration during production of the word "deer" and only 3 (MU, CR, and HL) for the word "kitkat". Therefore two aphasic speakers (MU, Broca's with AOS and CR, Broca's without AOS) consistently produced closure phases with increased variability. An increased closure duration did not correlate with an increase in the variability of closure duration which is contrary to the suggestions of Munhall (1982). He notes an "increase in variance as the mean increases" (p.67). FC, HJ and HL who produced increased variability on one of the two words were all diagnosed as anomic aphasics. Johns and Darley (1970) and Darley et al., (1982) suggest that AOS is characterized by increased variability which is supported by the data from MU. However FM, also diagnosed with AOS did not demonstrate increased temporal variability for any of the measures although his stop closure for the word "deer" was generally longer than the control speakers.

8.6.2.2 Proportion of the stop closure in relation to a word

The variability over ten repetitions for the proportion of the stop closure in relation to the whole word was calculated for productions of "deer". This measure was not considered to be affected by the rate of speech which was not controlled for. Only one conduction aphasic (IE) produced closures that were statistically different to the values calculated for the control speakers. Therefore although some subjects demonstrated an increased variability in temporal control for the initial closure this did not appear to affect the relationship between this phoneme and the rest of the word.

8.6.2.3 Are increased durations related to the area of lingual/palatal contact?

The subjects who demonstrated closure phases which were longer than the control speakers also appeared to produce patterns of contact with increased lingual/palatal contacts. Analysis of the lingual/palatal contacts for the /d/ closure in "deer" (see Figure 6-3, Chapter 3) suggests that MU, FM, CR, FC and HJ produce increased lateral contacts when compared to the control speakers (Figure 6-4, Chapter 4). Therefore we might suggest that an increase in duration is accompanied by an increase in lingual/palatal contacts. A lack of motor control may be responsible for the increase in contacts observed.

Four speakers from the control group (KM, LD, LE, WH) produced alveolar closure durations during repetition of the word "deer" which involved full contact over the first three rows of the palate in at least five of the total trials. The other control speakers used fewer alveolar contacts. The mean duration for these four control speakers were 0.106 msecs (KM), 0.076 msecs (LD), 0.112 msecs (LE) and 0.085 msecs (WH) (see Appendix D). The average duration for the other six control speakers (AM, FG, JS, PR, SN, WJ) was 0.110 msecs and +1 standard deviation was 0.137. It can be seen that none of the control speakers demonstrating increased contacts produced contact durations that were more than +1 standard deviation. All bar one, (LE, 0.112 msecs) were actually below the mean (0.110 msecs). Therefore the normal speakers do not demonstrate the same correlation between increased closure durations and increased contacts which was observed for the aphasic group.

Since some speakers produce velar closures beyond row 8 of the EPG palate comparison of the number of contacts for this phoneme is not possible.

8.6.3 Spatial variability

The aphasics demonstrated statistically greater spatial variability (as indicated by the VI scores) for the initial phoneme in "kitkat" but not in "deer". This increase in variability may be a result of impaired motor control. Individual scores revealed that more aphasics produced variability that was more than +1 standard deviation above the control mean for the word "kitkat" (MU, CR, IE, PW, HJ and HL) than for "deer" (CR, JM, IE and HJ). Surprisingly, those diagnosed with AOS did not consistently produce more variable articulations. MU (Broca's aphasic with AOS) produced contacts that were spatially more variable for "kitkat" but not for "deer". FM's VI scores (also a Broca's aphasic with AOS) were within the control norms for both words.

The aphasic speakers tended to produce alveolar closures with an increase in lingual/palatal contacts along the lateral margins irrespective of the variability of productions (Figure 6-3, Chapter 6). The prototypical EPG frame for each subject indicates that closure often involved two columns on either side of the palate compared to the control speakers who more frequently used a single column.

8.6.3.1 Relationship between temporal and spatial variability

An increase in spatial variability was not necessarily related to an increase in temporal variability and vice versa. Only one subject (HJ, anomic aphasic) showed an increase in variability for both dimensions during production of the word "deer". For "kitkat" all the speakers who demonstrated greater temporal variability (MU, CR, HL) also produced articulations considered to be more variable spatially. This would suggest that temporal programming and spatial programming of the tongue movements for speech sounds are controlled separately. This has been discussed by Edelman (1989) who suggests that the basal ganglia is involved in aspects of motor programming and sensory motor coordination (perhaps relating to lingual/palatal contacts) and the cerebellum is primarily concerned with the control of timing and synchronization of movements. CR, JM and IE are all known to have damage involving the basal ganglia and they all demonstrated spatial variability greater than the control subjects during production of the word "deer" (see Figure-4, Figure 6 and Figure 8, Appendix A, for CT scans of CR, JM and IE respectively). CR and IE were also more variable in their productions of "kitkat". This increase in variability coupled with the knowledge that the basal ganglia has been damaged lends support to Edelman's theory.

The type of variability appeared to be related to the target word. For example, more aphasics showed a statistical increase in variability in their temporal organization for the word "deer" (4/9) compared to spatial variability where only one subject was more than +1 standard deviation above the norm. In contrast, production of the word "kitkat" revealed that fewer aphasics (3/9) produced repetitions that were temporally more variable than spatially (6 aphasics).

8.6.4 Variability in the sequencing of two independent lingual gestures

Intra- and inter-subject variability of sequencing patterns used by both control and aphasic speakers during /kl/ and /tk/ targets was identified through analysis of the EPG data. This is not in keeping with an Articulatory Phonology point of view where each particular phasing relationship is implemented by a rule or rules specifying invariant coarticulation (Browman and Goldstein, 1990). It has been suggested that these phasing rules have access to three points in a gesture: onset, target and release. This over-restraining does not allow for the type of variability which was seen in this investigation and lends support to the view that Articulatory Phonology does not adequately explain the phasing of two gestures with its timing rules. A more probabilistic approach, as suggested by Byrd (1994) which allows for variance outside the lexicon, may be better at explaining the variability noted. She proposes a "Phase Window" which accounts for variability in a single assignment of a phasing relationship. This accounts for the invariance of temporal organization within the lexicon (e.g. VOT) and the non invariant inter-articulator phasing relationships outside the lexicon. Byrd (1996) states that "Competing linguistic and extra-linguistic influences that differ from utterance to utterance weight a phase window, determining where in the range of permissible overlap relationships a token will actually be realized" (p.241). This would permit the variability of sequencing patterns that was observed in the control and aphasic speakers.

8.6.5 Consistency of repetitions over time

Aphasic productions appeared to become more consistent over time both with regards to the duration of independent gestures and the sequencing of these. This was especially noticeable during productions of the WI /kl/ sequence (see Graph 6-3 to Graph 6-11 inclusive, Chapter 6). For example, FM's productions appear to become more consistent from repetition 7 to repetition 10 inclusive with respect to sequencing patterns (see Graph 6-3, Chapter 6). In repetition 1 FM produces a type 2 pattern (approach to the /l/ during the /k/ closure), repetition 2 is characterized by a type 5a pattern (omission of the velar), repetition 3 is a type 4 pattern (approach to the /l/ occurring prior to the onset of the /k/ closure), repetition 4 is a type 5a pattern, repetition 5 is a type 2 pattern and repetition 6 a type 4 sequencing pattern. Following this the final four repetitions are all characterized by a type 2 pattern where the approach to the /l/ can be seen during the /k/ closure period. Therefore FM's sequencing patterns become more consistent over time. This can also be clearly seen in FC's productions of "clock" (see Graph 6-9, Chapter 6). The first repetition is characterized by the omission of the lateral approximant and the production of a MAG which is of considerable duration (470 msecs). The velar closure occurs during this MAG so there is a period of double alveolar/velar articulation. Repetition 2 is a type 1 pattern (release of the /k/ prior to tongue tip/blade movement for the /l/). The following repetitions (R3 to R10) are all type 2 sequencing patterns (approach to the /l/ during the /k/ closure) of similar duration. Some aphasic speakers showed consistency in the pattern type but variable durations which became more consistent with successive repetitions. For example, the /l/ articulation during HL's first repetition of "clock" is much longer than the following productions (see Graph 6-11, Chapter 6). This continual rehearsal of the same word whose production became more consistent may indicate the construction of sensorimotor trajectories which then guided subsequent repetitions.

8.6.6 What causes variability?

One might predict that greater variability in the speech of neurologically impaired subjects is a reflection of the complexity of the word. An increase in the number of gestures and the sequencing of these presumably requires more complex motor programming. The increase in spatial variability for the word "kitkat" may be a reflection of the increased demands on the articulatory system and the spatial variability may suggest a lack of motor control. Alternatively, the increased variability may be related to the neuromuscular control specific to individual gestures. Activation of different muscles is required for the production of alveolar and velar plosives. The alveolar plosives require fine motor control from intrinsic muscles, specifically the longitudinalis superior muscle. In contrast, the velar articulations are achieved primarily by activity of the extrinsic muscles whose primary function is to alter the position of the tongue in the mouth, and perhaps also the inferior longitudinalis. However, to suggest that the more gross movements of the extrinsic muscles are impaired whilst the more fine tuning by the intrinsic muscles is preserved would seem counter intuitive.

8.7 Implications For Therapeutic Intervention

The results of this investigation suggest that the traditional linguistic-motoric dichotomy is too simplistic to explain the difficulties experienced following a CVA. The traditional syndromes that have been and still are used to describe patients following a CVA do not appear to be beneficial for descriptive or diagnostic purposes. They do not differentially diagnose the speech of the aphasics. In fact they appear to be misleading. Subjects with the same diagnosis rarely shared the same patterns of speech production and speech errors. Furthermore, phenomena that have been identified in earlier EPG studies of pure AOS, for example MAGs, were noted in the speech of all syndromes identified here through traditional assessment. Since it is usually the results of these tests from which therapeutic programs are devised, we may be creating treatment programs which are inappropriate and therefore ineffective and unefficacious.

8.8 Future Directions

This study has undertaken to investigate the speech of a range of aphasic subjects and a group of normal speakers using the technique of EPG. Differences and regularities between the speech of these two groups have been identified and also intra-subject differences within aphasic and control speakers. Attempts have been made to relate these observations to current models of speech production. However, analysis of the data has thrown out new ideas and areas of interest. Some suggestions for future research are discussed.

8.8.1 Subjects

8.8.1.1 Aphasic

One of the recognized limitations of this study was the small number of subjects that were investigated. More data from different aphasic speakers is necessary if we are to understand the disruptions in the speech of these patients. Whilst additional data from all aphasic syndromes would be beneficial to the development of theories of speech production in acquired neurogenic disorders, it would be interesting to group subjects on the basis of their brain damage as opposed to traditional classifications. The results of the current study have shown that errors are often subject specific and not related to a particular aphasic syndrome but there appears to be some similarities between subjects with corresponding areas of brain damage. These traditional classifications tell us very little about the errors these subjects produce nor the processes of speech production that have been damaged. Investigations which group patients on the basis of brain lesions may highlight similarities between aphasic subjects. Close liaison with neurologists would assist in a better understanding of brain damage and its affects on the control of speech. MRI scans in addition to CT scans would help in the identification of areas of damage since they provide a much clearer image of the cerebellum.

8.8.1.2 Control

There have been few studies that have systematically collected data from large numbers of normal speakers. More recordings are necessary to provide accurate norms and measures of variability especially since variability is often a "primary concern in clinical assessment" (Munhall, 1989: p.64). Without reliable measures of normal variability we are not in a position to decide whether disordered speech is more variable or not. Specifically we need to quantify the range of closure durations for a variety of stops and the variability of the lingual/palatal contact patterns.

All EPG recordings of normal speakers to date have been concerned with correct speech productions. There have been no studies investigating errors, for example, slips of the tongue. In this thesis it has been suggested that the production of MAGs is a characteristic of the speech of adults with acquired neurogenic speech disorders since they have never been identified in normal EPG data. It would be interesting to record slips of the tongue from normal speakers and to analyse the EPG patterns during these. Of particular interest would be whether MAGs occur during these errors. Dell (1986, 1989) and Schwartz et al. (1994) have administered experiments which have elicited slips of the tongue to test the validity of Dell's model of ISA. If similar procedures were employed during EPG recordings would MAGs occur in the speech of normal adults? Identification of these error types would have important implications for the development of models of speech production.

8.8.2 Speech data

This study has been concerned with the production of single words. This is useful since it eliminates the possibility of errors arising at a syntactic level of processing. This is not to suggest that sentence data is uninformative but simply that it poses additional difficulties during analysis. It is perhaps easier to propose whether an error is a result of a linguistic or a motoric deficit in single words where there are no syntactic influences. However, analysis of sentences can provide additional information especially with respect to coarticulation which was of interest in this investigation.

It has been suggested that some aphasic speakers experience difficulty in the sequencing of successive lingual phonemes. This was evidenced by the additional sequencing patterns which were only identified in the speech of the aphasic group not the control speakers. Ingram and Hardcastle (1990), on the basis of recordings from a single subject with acquired AOS, suggested that these speakers have particular difficulty in the sequencing of velar and alveolar phonemes across a morpheme boundary in word medial position. Both normal and disordered data on sequencing of phonemes are limited and comparison is difficult due to differences in annotation. It would be interesting to record a number of different alveolar/velar and velar/alveolar sequences with a variety of syntactic boundaries between the gestures to more fully assess the ability of aphasic speakers to coarticulate. The types of errors produced seem particularly informative in identifying the level of breakdown in aphasic speech.

8.8.3 Instrumentation

Whilst EPG is an important tool in speech research it has a number of limitations. Firstly, it provides no information on the proximity of the tongue with the palate. Also of importance is that it fails to record contacts in the velar region when they are beyond the back of the palate. Simultaneous recordings with other instrumentation such as the electromagnetic articulogram (EMA) (Stone, 1997) would provide additional informative data. EMA tracks the movement along a mid-saggital plane of small receiver coils, sutured to different articulators, through alternating magnetic fields. With respect to the tongue, it can provide additional information on position within the oral cavity, proximity of the tongue with the hard and soft palate and movements of the tongue in relation to other articulators such as the lips. It would be particularly interesting to investigate whether there is any movement of the tongue during errors of omission identified through EPG. Furthermore, it may identify the presence of MAGs produced by other articulators, for example the lips. Such combined EMA and EPG recordings have been carried out on normal speakers (Hoole, 1993) providing a more complete picture of complex articulators.

Chapter 9

9. Conclusions

This investigation has examined in detail the lingual/palatal contact patterns produced by a range of aphasic speakers. The results challenge the motoric/linguistic dichotomy which has traditionally separated AOS from other aphasic syndromes outlined by Goodglass and Kaplan (1972). Specifically the errors that were revealed through analysis of the EPG data could not separate the different classification of subjects The main findings in relation to the research questions which were outlined in Section 1.1.2 will be summarized.

Analysis of the EPG data has revealed speech errors which were not detected through auditory-based analyses (MAGs). A detailed look at a small subset of substitutions which were identified through auditory perceptual analysis indicated that 25% of the so-called "pure" substitutions involved additional abnormal lingual/palatal contacts. MAGs were also noted when correct productions were assumed from auditory analysis. These observations have important implications for understanding the level of impairment and the subsequent development of models of speech production. A substitution has been taken as evidence for a linguistic deficit suggesting that the aphasic speaker has selected the incorrect phoneme during the process of phonological encoding. According to Dell's model of ISA this arises from selecting the phoneme with the highest level of activation at the decision stage following feedforward and feedback processes. However, the identification of these additional lingual/palatal contacts undermines Dell's explanation and modifications to his model of ISA are necessary to enable these errors to be explained at the level of phonological encoding. For example, it has been suggested that perhaps two phonemes are selected at the decision stage because they share equal levels of activation. These modifications, along with the elimination of the position encoding constraint were also suggested to explain the presence of MAGs where no substitution was identified on auditory analysis. Alternatively we could suggest that the additional contacts are actually at the level of motor programming. Following selection of the correct phoneme the articulators are incorrectly positioned which produces the additional lingual/palatal contacts that were noted through analysis of the EPG data.

Increased variability has frequently been associated with apraxic speech (Duffy and Gawle, 1984; McNeil et al., 1989; Odell et al., 1990; Hardcastle and Edwards, 1992; Seddoh et al., 1996). This was not a consistent feature of the lingual/palatal contact patterns in this study, nor did it separate AOS from the other subjects. Whilst the aphasic group generally made stop closures with an increase in duration of contacts this did not assume increased temporal variability. One subject diagnosed as Broca's with AOS (MU) and one Broca's without AOS (CR) appeared consistently more variable during their productions of the two stop closures that were examined. However, productions by FM (Broca's with AOS), and JM (Broca's without AOS) were not considered more variable than the control speakers. Therefore no one classification showed consistently increased temporal variability.

More subjects demonstrated increased spatial variability than temporal, but again this was not a diagnostic feature for any particular classification. Three subjects, CR, IE and HJ with varying diagnoses (Broca's without AOS, conduction aphasic and anomic respectively) were consistently more variable in the spatial arrangement of their lingual/palatal contact patterns when compared to the control group. Three additional subjects were more variable during production of the WI stop in "kitkat" but not "deer" (MU, Broca's with AOS, PW, conduction aphasic, HL, anomic). Therefore increased complexity of the target word evidenced greater variability from a range of aphasic speakers. The increased spatial variability, similar to the temporal variability was not confined to those subjects diagnosed with AOS or Broca's aphasia. However, CT scans which were available for those subjects whose productions were more variable indicated damage to the basal ganglia. This lends support to the views of Edelman (1989) who suggested the basal ganglia was involved in aspects of motor programming. In addition, it should be noted that an increase in temporal variability did not assume an increase in spatial variability which suggests that temporal and spatial programming of the tongue are controlled separately.

Whilst the aphasic group did show differences in the sequencing and timing of the tongue tip/blade and tongue body in consonant sequences compared to the control group, the difficulties experienced were not specific to any one syndrome. As a group the aphasic speakers less frequently coarticulated sequential alveolar and velar or velar and alveolar phonemes. Furthermore, many erroneous patterns were identified for both /kl/ and /tk/ sequences compared to the control group. More sequencing errors were noted for the WI /kl/ sequence than for the /tk/ sequence which crossed a morpheme boundary. Ingram and Hardcastle (1990) suggested that apraxic speakers avoid temporal overlap. This avoidance was not a consistent feature of those subjects with AOS examined in this investigation. One Broca's aphasic with AOS, FM, frequently coarticulated adjacent consonants both in WI position and across a morpheme boundary. In contrast, MU appeared to avoid temporal overlap. Therefore the results do not support the claims of Ingram and Hardcastle (1990). A consistent feature which was noted was the increased latencies across a morpheme boundary produced by conduction aphasics in the absence of erroneous sequencing patterns. The difficulties of phonetic sequence management in conduction aphasia were stated by Kent (1990). He suggested that this could result from lesions to the supramarginal postcentral gyrus or the arcuate fasciculus. Unfortunately this information was not available from the CT scans.

The results from this study have suggested that the speech errors produced by a range of aphasic speakers cannot be associated with a particular aphasia syndrome. Instead the errors appeared to be subject specific and often related to site of brain lesion. The motoric/linguistic dichotomy which has traditionally been used to describe and separate the speech errors of AOS and phonemic paraphasia has been challenged. The range of subjects in this thesis showed similarities in the types of errors detected through electropalatography. It is suggested that this is evidence for a motoric/linguistic continuum which is related to site of brain lesion. It is concluded that the traditional classifications proposed by Goodglass and Kaplan (1972) and the description of non-fluent versus fluent speech disorders in aphasia is neither diagnostically nor descriptively adequate and leads to misconceptions about aphasic impairment. These misunderstandings need to be avoided if we are to develop comprehensive models of speech production able to explain pathological speech. Furthermore, incorrect diagnosis will result in establishing inappropriate and unefficacious therapeutic intervention programs.

Appendix A

FM (Broca's aphasic with AOS)

Boston Diagnostic Aphasia Examination

Conversational And Expository Speech

FM fall

and er dishes

er water

garden

cookie jar

SLT Where is the scene set?

FM kitchen

girl and boy

SEVERITY RATING	1
AUDITORY COMPREHENSION	Scores at or above the 80th %tile for all subtests. Occasionally responses were delayed during word discrimination and body part identification tasks, but never incorrect. Some difficulty with longer complex ideational material.
ORAL EXPRESSION	Severe articulatory difficulties characterised by groping of the articulators, repetition of sounds and a decreased rate of speech. Some phonemic paraphasia. Repetition of longer phrases was impaired. Poor short term memory was felt to be a contributing factor especially since low probability sentences caused greater problems than high.. Difficulty reading function words.
UNDERSTANDING WRITTEN LANGUAGE	Scored well on matching words and symbols, identifying written words and word picture matching. Most difficulty with comprehension of oral spelling and reading sentences and paragraphs, typically choosing the semantic distracter during the latter. Longer paragraphs not tested due to reading deficits.
WRITING	Writing was with the non preferred hand. Better formation when copying than self generation. Great difficulty with all subtests except transcribing a sentence.

Table 1: Summary of BDAE for FM.

BDAE *Rating Scale Profile of Speech Characteristics*

SEVERITY RATING	**1**		
MELODIC LINE	1 2 3 4 5 6 7 absent	Limited to short phrases and stereotypes	Runs through entire sentence
PHRASE LENGTH	1 word	4 words	7 words
ARTICULATORY AGILITY	Always impaired or impossible	Normal only in familiar words and phrases	Never impaired
GRAMMATICAL FORM	None available	Limited to simple declaratives and stereotypes	Normal range
PARAPHASIA IN RUNNING SPEECH	Present in every utterance	Once per minute of conversation	absent
REPETITION	0 0 1 2 4 5 6 8		
WORD FINDING	Fluent without information	Information proportional to fluency	Speech exclusively content words
AUDITORY COMPREHENSION	1 15 30 45 60 75 86.25 90		
VOLUME	Hypophonic	**Normal**	Loud
VOICE	Whisper	**Hoarse**	Normal
RATE	**Slow**	Normal	Rapid

Table 2: BDAE Rating Scale Profile of Speech Characteristics for FM (Goodglass and Kaplan, 1972).

BDAE Subtest summary profile

	PERCENTILES	0		10		20		30		40		50		60		70		80		90		100
SEVERITY RATING				0		1								2				3		4		5
FLUENCY	ARTICULATORY RATING			1		2		4		5		6				7						
	PHRASE LENGTH					1		3		4		5		6		7						
	MELODIC LINE			1		2		4				6		7								
	VERBAL AGILITY			0		2		5		6	7	8		9		11		13		14		
AUDITORY COMPREHENSION	WORD DISCRIMINATION	0		15		25		37		46		53		60		64		67		70		72
	BODY-PART IDENTIFICATION	0		1		5		10		13		15		16		17		18				20
	COMMANDS	0		3		4		6		8		10		11		13		14		15		
	COMPLEX IDEATIONAL MATERIAL			0		2		3		4		5		6		8		9		11		12
NAMING	RESPONSIVE NAMING					0		1		5		10		15		20		24		27	28	30
	CONFRONTATION NAMING			0		9		28		43		60		72		84		94		105	109	114
	ANIMAL NAMING							0		1		2		3		4		6		9		23
ORAL READING	WORD READING					0		1		3		7		15		21		26	28	30		
	ORAL SENTENCE READING									0		1		2		4		7		9		10
REPETITION	REPETITION OF WORDS			0		2		5		7		8				9				10		
	HIGH-PROBABILITY					0		1				2		4		5		7		8		
	LOW-PROBABILITY									0		1				2	3	4		6		8
PARAPHASIA	NEOLOGISTIC	40		16		9		4		2		1				0						
	LITERAL	47		17		12		9		6		5		3		2		1		0		
	VERBAL	40		23		18		15		12		9		7		4		3		1		0
	EXTENDED	75		12		5		3		1		0										
AUTOMATIC SPEECH	AUTOMATIZED SEQUENCES			0		1		2		3		4		6		7				8		
	RECITING							0		1								2				
READING COMPREHENSION	SYMBOL DISCRIMINATION	0		2		5		7		8		9				10						
	WORD RECOGNITION	0		1		3		4		5		6		7				8				
	COMPREHENSION OF ORAL SPELLING							0		1				3		4		6		7		8
	WORD-PICTURE MATCHING			0		1		4		6		8		9				10				
	READING SENTENCES & PARAGRAPHS			0		1		2		3		4		5		6		7		8		10
WRITING	MECHANICS	1				2				3				4						5		
	SERIAL WRITING			0		7		18		25		30		33		40		43		46		47
	PRIMER-LEVEL DICTATION			0		1		4		6	8	9		11		13		14		15		
	SPELLING TO DICTATION									0		1		2		3		5		7		10
	WRITTEN CONFRONTATION NAMING							0		1		2		3		6		7		9		10
	SENTENCES TO DICTATION											0		1		3		6		8		12
	NARRATIVE WRITING (not tested)			0		1						2						3		4		
MUSIC	SINGING			0		1				2												
	RHYTHM			0		1								2								
		0		10		20		30		40		50		60		70		80		90		100

Table 3: BDAE Subtest summary profile for FM (Goodglass and Kaplan, 1972).

Frenchay Dysarthria Profile

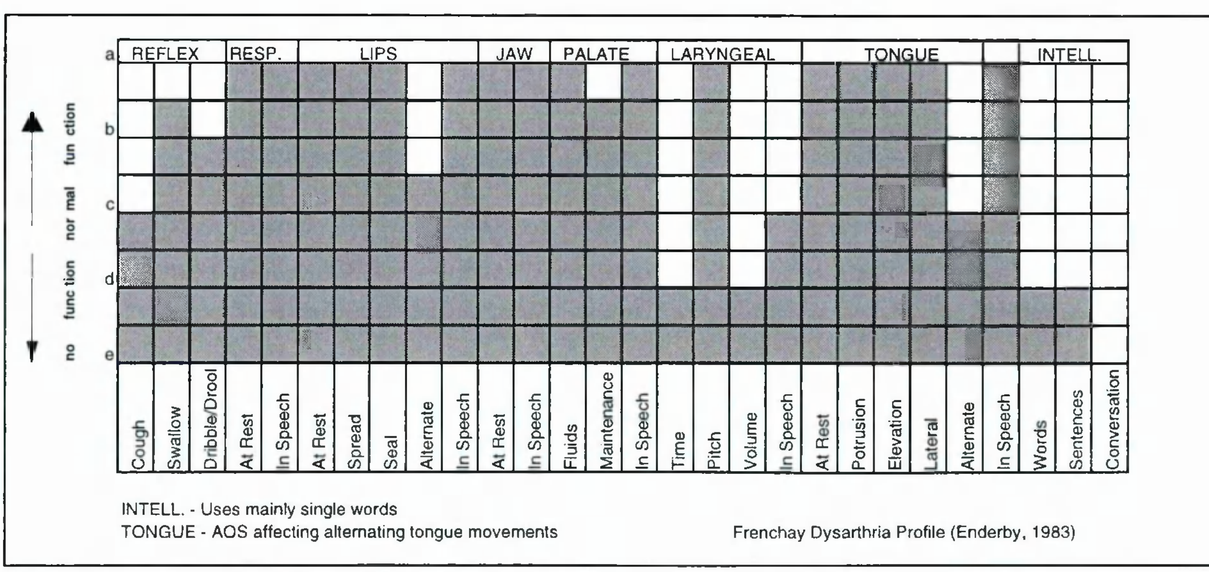


Figure 1: Frenchay Dysarthria Profile for FM (Enderby, 1983).

Phonetic transcriptions

Word List A

	Orthographic	Repetition 1	Repetition 2
1.	a dart	daɹt	a daɹt
2.	a tip	a: tʰɪp	a tʰɪp
3.	a leg	a: lɛg̊	a lɛg̊˺
4.	a deer	a: diɾ	a: diɾ
5.	a chain	a: tʃen	a: dʲen
6.	a shark	a: ʃa:ɹp	a: tʃaɹp
7.	a key	a: kʰi	a: ə di: ə k̬i
8.	the dolls	ðə dɔ	a d/dɔ
9.	a gear	a: diɾ	a diɾ
10.	a book	a: buk	a: fbuɰk
11.	a car	g̊aɾ	a: k̬aɾ
12.	a beak	a: (..) bik	a bi:k
13.	a knot	a: nɔt	a: nɔt
14.	the dark	a sda:t˺k	ðə daɹk
15.	a tick	a t̬ɪk	a: tʰɪk
16.	near	aɹ̩ niɾ	niɾ
17.	sea	a: sisaɪd	a sʲi
18.	she	ʃi	ʃi
19.	a tear	a tiɹ	a: ə̆ t̬iɹ
20.	the sun	a sʌn	ðə sʌn
21.	a mouse	a mausʲ	a: mɑus
22.	a cheer	a: tʃ:iɾ	a: ʃiɾ
23.	a fish	a: sfɪʃ	a: (...) fɪʃ
24.	a zoo	a z̬u:	a: z̥u:
25.	a sheep	a si:p	a: çip
26.	a brush	a: fɜɹs	a: bɹʌʃ
27.	a leer	a liɾ	a: ʃɹiɾ
28.	a seed	a: si:d̥	a sid
29.	a shop	a: sɔp	a: ʃɔp
30.	a racer	a: zɹezɪɹ baɪk	a: ɹezɜ
31.	a leaf	a: zɹi:f	a ʃɹi:f:

Table 4: Phonetic transcription of word list A produced by FM.

Word List B

	Orthographic	Repetition 1	Repetition 2
1.	a cocktail	a: ʃkʰɔktɛə	a kʰɔk˺kel
2.	a kitkat	a: kʰ:ɪkat	a kʰɪt˺k̬at
3.	a clock	a: k̬lɔ̃k	a kʰəlɔk
4.	a headlight	a: hɛd˺dɹaɪt	a hed˺fɹaɪt
5.	a tractor	a: t:ʰɹaktɜ	a: tɹaktɜ
6.	a weekday	a: βwi:kdeɪ	a: ɸwi:kde
7.	a tickling	a tɹɪkl	a: tsɜ:kl̩
8.	a deckchair	a dɛktʃeə	a tʃɛk˺tʃeə
9.	a witchcraft	a dɹ:ɪʃqɹaf	a: ɸɹɪsʃka:f
10.	a bookshop	a bukʃɔp	a: bukʃɔp
11.	a star	a staɹ	a: s:ta:ɹ
12.	a box	a bɔkts	a bɔ:ks
13.	the hats	a hæt	ðə hʌt
14.	a squashkit	a: sw:ɔskɪt	a: χkwɔʃkɪt a: skwɔ:ʃkɪt
15.	a skirt	a: sf gək	a: xskɜ:t
16.	a catkin	a skat˺k̬ɪn	a: tkat˺kɪn

Table 5: Phonetic transcription of word list B produced by FM.

Phonetic transcriptions

Repetitions

“deer”	
Repetition	Phonetic Transcription
1.	a: diɾ
2.	a: diɾ
3.	a: diɾ
4.	a: diɾ
5.	a: diɾ
6.	a: diɾ
7.	a: diɾ
8.	a: diɾ
9.	a: diɾ
10.	a: diɾ

“clock”	
Repetition	Phonetic Transcription
1.	a glɔk
2.	a dɹɔk
3.	a klɔk
4.	a lɔk
5.	a kʰəlɔk
6.	a kʰəlɔk
7.	a klɔk
8.	a klɔk
9.	a kʰəlɔk
10.	a klɔk

“kitkat”	
Repetition	Phonetic Transcription
1.	a kʰɪʔkat
2.	a kʰɪʔkat
3.	a kʰɪʔkat
4.	a kʰɪt̚kat
5.	a kʰɪt̚kat
6.	a kʰɪtkat
7.	a kʰɪt̚kat
8.	a kʰɪʔkat
9.	a kʰɪtkat
10.	a kʰɪʔkat

Table 6: Phonetic transcription of the repetition task produced by FM.

MU (Broca's aphasic with AOS)

Boston Diagnostic Aphasia Examination

Conversational And Expository Speech

MU That's er _ _ _ [m:] _ _ _ that's um boys _ _ _ girls

and er

[tə tə tu:] no [kʰ/kʰ] cookie

That's is the er _ _ [wɒsɛm]

He's er _ _ _ [wʌnɪŋ ðə] no

it's er [wəgə u:]

it's er _ _ _ um _ _ is er [baɪ ɪŋ]

that's right

is er _ _ _ (laughs) um _ _ er _ _ _ I think [sɪp]

SEVERITY RATING	1
AUDITORY COMPREHENSION	Good auditory comprehension. Occasional left / right confusion when asked to identify body parts. Some confusion with complex ideational material.
ORAL EXPRESSION	Able to perform the non-verbal oral agility tasks easily and at speed, but had great difficulty with the verbal component demonstrating much groping, substitution of phonemes and a decreased rate. Performance was suggestive of apraxia of speech in the absence of any oral apraxia. Automatic speech was impaired. Only able to recite the days of the week. All subtests in the Oral Expression section highlight extreme articulatory impairment.
UNDERSTANDING WRITTEN LANGUAGE	Some difficulty with phonetic association and reading sentences and paragraphs.
WRITING	Writes legibly with non preferred hand. Difficulty with all sections except transcription.

Table 7: Summary of BDAE for MU.

BDAE Rating Scale Profile of Speech Characteristics

SEVERITY RATING	**1**		
MELODIC LINE	1 2 3 4 5 6 7 absent · Limited to short phrases and stereotypes · Runs through entire sentence		
PHRASE LENGTH	1 word · 4 words · 7 words		
ARTICULATORY AGILITY	Always impaired or impossible · Normal only in familiar words and phrases · Never impaired		
GRAMMATICAL FORM	None available · Limited to simple declaratives and stereotypes · Normal range		
PARAPHASIA IN RUNNING SPEECH	Present in every utterance · Once per minute of conversation · absent		
REPETITION	0 0 1 2 4 6 8		
WORD FINDING	Fluent without information · Information proportional to fluency · Speech exclusively content words		
AUDITORY COMPREHENSION	59.5 1 15 30 45 60 75 90		
VOLUME	Hypophonic	**Normal**	Loud
VOICE	Whisper	Hoarse	**Normal**
RATE	**Slow**	Normal	Rapid

Table 8: BDAE Rating Scale Profile of Speech Characteristics for MU (Goodglass and Kaplan, 1972).

BDAE Subtest summary profile

	PERCENTILES	0		10		20		30		40		50		60		70		80		90		100
SEVERITY RATING				0		**1**								2				3		4		5
FLUENCY	ARTICULATORY RATING			1		**2**		4		5		6				7						
	PHRASE LENGTH					1		**3**		4		5		6		7						
	MELODIC LINE			1		**2**		4				6		7								
	VERBAL AGILITY			0		2	**3**	5		6		8		9		11		13		14		
AUDITORY COMPREHENSION	WORD DISCRIMINATION	0		15		25		37		46		53		60	**62**	64		67		70		72
	BODY-PART IDENTIFICATION	0		1		5		10		13		**15**		16		17		18				20
	COMMANDS	0		3		4		6		**8**		10		11		13		14		15		
	COMPLEX IDEATIONAL MATERIAL			0		2		3		4		5		6		**8**		9		11		12
NAMING	RESPONSIVE NAMING					0		1		5		10		15		20	**21**	24		27		30
	CONFRONTATION NAMING			0		9		28		43		60	**66**	72		84		94		105		114
	ANIMAL NAMING							0		1		**2**		3		4		6		9		23
ORAL READING	WORD READING					0		1		3		7		15	**19**	21		26		30		
	ORAL SENTENCE READING									0		1		**2**		4		7		9		10
REPETITION	REPETITION OF WORDS			0		2		**5**		7		8				9				10		
	HIGH-PROBABILITY					**0**		1				2		4		5		7		8		
	LOW-PROBABILITY									**0**		1				2		4		6		8
PARAPHASIA	NEOLOGISTIC	40		16		9		4		2		1				**0**						
	LITERAL	47	**23**	17		12		9		6		5		3		2		1		0		
	VERBAL	40		23		18		15		12		9		7		4		3		1		**0**
	EXTENDED	75		12		5		3		1		**0**										
AUTOMATIC SPEECH	AUTOMATIZED SEQUENCES			0		1		**2**		3		4		6		7				8		
	RECITING							**0**		1								2				
READING COMPREHENSION	SYMBOL DISCRIMINATION	0		2		5		7		**8**		9				10						
	WORD RECOGNITION	0		1		3		4		**5**		6		7				8				
	COMPREHENSION OF ORAL SPELLING							0		1				3		4	**5**	6		7		8
	WORD-PICTURE MATCHING			0		1		4		6		8		**9**				10				
	READING SENTENCES & PARAGRAPHS			0		1		2		3		4		5		6		**7**		8		10
WRITING	MECHANICS	1				2				3				**4**						5		
	SERIAL WRITING			0		7		18	**21**	25		30		33		40		43		46		47
	PRIMER-LEVEL DICTATION			0		1		4		6	**7**	9		11		13		14		15		
	SPELLING TO DICTATION									0		1		**2**		3		5		7		10
	WRITTEN CONFRONTATION NAMING							0		1		2		3		6		**7**		9		10
	SENTENCES TO DICTATION (not tested)											0		1		3		6		8		12
	NARRATIVE WRITING			0		1						**2**						3		4		
MUSIC	SINGING			**0**		1				2												
	RHYTHM			**0**		1								2								
		0		10		20		30		40		50		60		70		80		90		100

Table 9: BDAE Subtest summary profile for MU (Goodglass and Kaplan, 1972).

Frenchay Dysarthria Profile

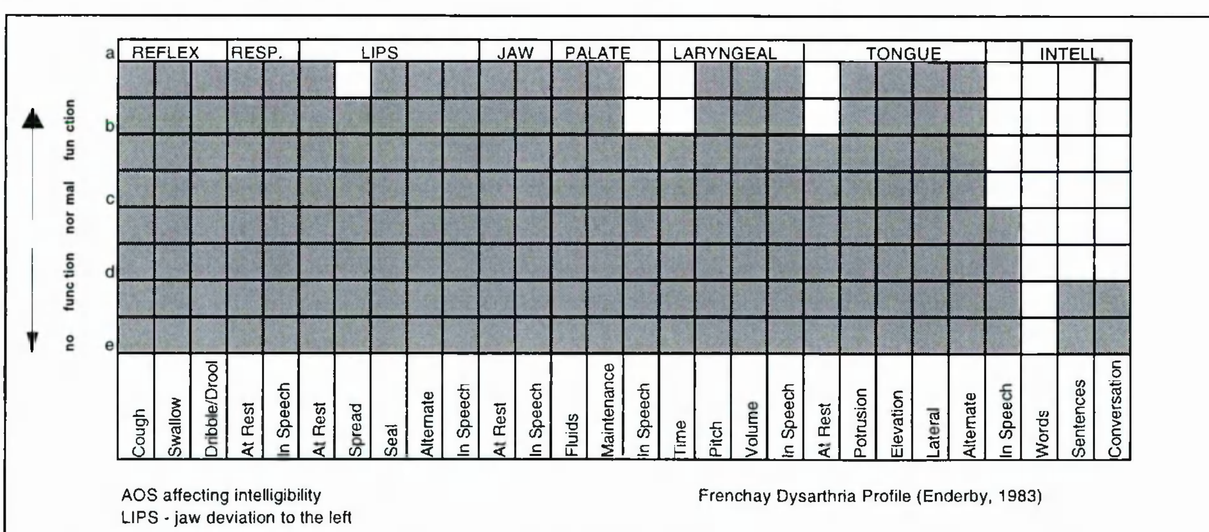


Figure 2: Frenchay Dysarthria Profile for MU (Enderby, 1983).

Phonetic transcriptions

Word List A

	Orthographic	Repetition 1
1.	a dart	ʌ d:aɹt
2.	a tip	ʌ tʰɪp
3.	a leg	ʌ l̩/l̩/lɛnt
4.	a deer	ʌ deɹ
5.	a chain	ʌ t:ʃen
6.	a shark	ʌ t:ʃaɹt
7.	a key	ʌ tʰi
8.	the dolls	ðə tɔl̩n̩s
9.	a gear	ə diɹ
10.	a book	ə put
11.	a car	ə tʰaɹ
12.	a beak	ə ɸ/pi:pt
13.	a knot	ə dɔ̃n̩t
14.	the dark	ðə t̪aɹt
15.	a tick	ðə tʰɪt
16.	near	niɹ
17.	sea	ðə si
18.	she	si
19.	a tear	ʌ t̪ iɹ
20.	the sun	ðə s/sʌn
21.	a mouse	ʌ mʌzn̩s
22.	a cheer	ʌ tʰiɹ
23.	a fish	ʌ s:ɪns
24.	a zoo	ə su
25.	a sheep	ðə (..) sɪp
26.	a brush	ðə bɹʌns
27.	a leer	ðə liɹ
28.	a seed	ðə s:iɹt
29.	a shop	ðə s:pə s:ɔp
30.	a racer	ðə ɹezsɛɹ
31.	a leaf	ðə βɹis

Table 10: Phonetic transcription of word list A produced by MU.

Word List B

	Orthographic	Repetition 1	Repetition 2
1.	a cocktail	ʌ ɸtɔteɹ	ðə ts tə ʌ tʰɔktɛl ðə kɛt˺n̩teɹ
2.	a kitkat	ʌ t:sɪk:at ʌ kʰ/kʰɪtdat	ðə (..) kʰɪttat
3.	a clock	ʌ t:ɹɔk	ʌ kʰɔk
4.	a headlight	ʌ ʃɹɪdkat ʌ ɹikaɹɹat	ðə θseks.gant
5.	a tractor	ʌ dɹeʔdɹɔ:	ðə sɹɹat˺tɛ
6.	a weekday	wikdɹe	ðə wi:kde
7.	a tickling	ʌ t:ɹ:ɪk˺kɹɪn	ðə kɹɪktɹɪn
8.	a deckchair	ʌ dɹɪk.tʲeə	ðə tɹɪktɹɪn
9.	a witchcraft	ðə ɹɪtstɹfads	ðə wɪtsk̪ɹans
10.	a bookshop	ðə ɸuts.tkɹɔt	ðə ɸʌtsk̪ɹans
11.	a star	ðə s:ta	s:ka
12.	a box	ðə ɸɔts	s: ʌ ɸɔts
13.	the hats	ðə s: (..) hats	ðə (..) hats
14.	a squashkit	tswɔtsɪgt ɸswɔzsɪgs	ðə s:kwɔts.kɪt
15.	a skirt	ðə s:kat	ðə skɛt
16.	a catkin	ðə t kʰʌtgɪd̪s	k ʌ kʰantʰtəkɪn

Table 11: Phonetic transcription of word list B produced by MU.

Phonetic transcriptions

Repetitions

"deer"	
Repetition	Phonetic Transcription
1.	ə d̥iɹ
2.	ðə diɹ
3.	ðə tʰiɹ
4.	ðə t͡giɹ
5.	ðə tʰiɹ
6.	ðə diɹ
7.	ðə diɹ
8.	ðə d̥iɹ
9.	ðə diɹ
10.	ðə d̥iɹ

"clock"	
Repetition	Phonetic Transcription
1.	ðə kʰɔk
2.	ə t͡kʰɔk
3.	ðə kʰɔk
4.	ðat t̬ɹɔk
5.	ðə t͡jɹɔk
6.	ðə xɹɔk
7.	ðə kɹɔk
8.	ðə kɹɔk
9.	ðə tʰəɹɔk
10.	ðə tɹɔk

"kitkat"	
Repetition	Phonetic Transcription
1.	tkʰɪtdat
2.	ə tkʰɪt̚tʰat
3.	ðə kʰɪtkʰat
4.	ðə kʰɪt̚kʰat
5.	ðə kɪt͡tat
6.	ə kʰɪt̚katʰ
7.	ðə kʰɪʔgat
8.	ðə kʰɪd̚gat
9.	ðə kʰɪt̚dat
10.	ə kʰɪt̚gat

Table 12: Phonetic transcription of the repetition task produced by MU.

BA (Broca's aphasic without AOS)

Boston Diagnostic Aphasia Examination

Conversational And Expository Speech

BA	girl washing up
	and er forgotten name
	water?
	something like but not quite maybe
	nothing much here
	and um cookie jar
	and er not daughter
	only twelve or something like
	and daughter and son but only twelve
	forgotten name again
	and this one second
	out
SLT	what are the children trying to do?
	er cookie [bɑɹ]
	er this I think there and maybe more
	there two cookies anyway
	one two
SLT	you think he's gonna give some to the girl?
BA	yes
	forgotten name (points to water)
	open still
	tap closed really
	and er forgotten name
	one word
SLT	water?
BA	yes water
	well nothing else really

SEVERITY RATING	4
AUDITORY COMPREHENSION	Particular difficulty identifying body parts, complex ideational material and executing longer commands. The latter is felt to be a result of limited short term memory (STM)
ORAL EXPRESSION	Decreased rate of oral agility for both verbal and non verbal tasks. Completed all automatized sequences and words in repetition. Repetition of sentences difficult, probably due to poor STM. All naming tests proved difficult highlighting word finding difficulties. Certain semantic fields were more problematic than others, (e.g. colours and body parts), but named many animals (score >90%tile). Occasional phonemic paraphasia.
UNDERSTANDING WRITTEN LANGUAGE	Performance on syllable discrimination, word recognition, comprehension of oral spelling and word picture matching was good. Great difficulty reading sentences and paragraphs - unable to access semantic system efficiently.
WRITING	No difficulty with serial writing but problems with all other subtests. Unable to spell any words to dictation which suggests problems at the phoneme to grapheme level. Could not attempt narrative writing.

Table 13: Summary of BDAE for BA.

BDAE Rating Scale Profile of Speech Characteristics

SEVERITY RATING	**4**		
MELODIC LINE	1 2 3 4 5 6 7		
	absent	Limited to short phrases and stereotypes	Runs through entire sentence
PHRASE LENGTH	1 word	4 words	7 words
ARTICULATORY AGILITY	Always impaired or impossible	Normal only in familiar words and phrases	Never impaired
GRAMMATICAL FORM	None available	Limited to simple declaratives and stereotypes	Normal range
PARAPHASIA IN RUNNING SPEECH	Present in every utterance	Once per minute of conversation	absent
REPETITION	0 0 1 2 4 6 8		
WORD FINDING	Fluent without information	Information proportional to fluency	Speech exclusively content words
AUDITORY COMPREHENSION	1 15 30 45 60 75 90		
VOLUME	Hypophonic	**Normal**	Loud
VOICE	Whisper	Hoarse	**Normal**
RATE	Slow	Normal	Rapid

Table 14: BDAE Rating Scale Profile of Speech Characteristics for BA (Goodglass and Kaplan, 1972).

BDAE Subtest summary profile

	PERCENTILES	0	10	20	30	40	50	60	70	80	90	100
SEVERITY RATING			0	1				2		3	**4**	5
FLUENCY	ARTICULATORY RATING		1	2	4	5	**6**		7			
	PHRASE LENGTH			1	3	4	5	6	**7**			
	MELODIC LINE		1	2	4		6	**7**				
	VERBAL AGILITY		0	2	5	6	**8**	9	11	13	14	
AUDITORY COMPREHENSION	WORD DISCRIMINATION	0	15	25	37	46	53	60 **6**	64	67	70	72
	BODY-PART IDENTIFICATION	0	1	5	**10**	13	15	16	17	18		20
	COMMANDS	0	3	4	6	8 **9**	10	11	13	14	15	
	COMPLEX IDEATIONAL MATERIAL		0	2	3	4	5	6 **7**	8	9	11	12
NAMING	RESPONSIVE NAMING			0	1	5	10	15	20 **21**	24	27	30
	CONFRONTATION NAMING		0	9	28	43	60	72 **79**	84	94	105	114
	ANIMAL NAMING				0	1	2	3	4	6	9 **14**	23
ORAL READING	WORD READING			0	1	3	7	15	21	26	**30**	
	ORAL SENTENCE READING					0	1	2	4 **6**	7	9	10
REPETITION	REPETITION OF WORDS		0	2	5	7	**8**		9		10	
	HIGH-PROBABILITY			0	1		**2**	4	5	7	8	
	LOW-PROBABILITY					0	**1**		2	4	6	8
PARAPHASIA	NEOLOGISTIC	40	16	9	4	2	1		**0**			
	LITERAL	47	17	12	9 **7**	6	5	3	2	1	0	
	VERBAL	40	23	18	15	12	9	7	4	3	**1**	0
	EXTENDED	75	12	5	3	1	**0**					
AUTOMATIC SPEECH	AUTOMATIZED SEQUENCES		0	1	2	3	4	6	7		**8**	
	RECITING				0	**1**				2		
READING COMPREHENSION	SYMBOL DISCRIMINATION	0	2	5	7	8	9		**10**			
	WORD RECOGNITION	0	1	3	4	5	6	7		**8**		
	COMPREHENSION OF ORAL SPELLING				0	1		3	**4**	6	7	8
	WORD-PICTURE MATCHING		0	1	4	6	8	9		**10**		
	READING SENTENCES & PARAGRAPHS		0	1	2	**3**	4	5	6	7	8	10
WRITING	MECHANICS	1		2		3		**4**			5	
	SERIAL WRITING		0	7	18	25	30	33	40	43	46	**47**
	PRIMER-LEVEL DICTATION		0	1	4	6	**9**	11	13	14	15	
	SPELLING TO DICTATION					**0**	1	2	3	5	7	10
	WRITTEN CONFRONTATION NAMING				0	1	2	3 **4**	6	7	9	10
	SENTENCES TO DICTATION						0	**1**	3	6	8	12
	NARRATIVE WRITING		**0**	1			2			3	4	
MUSIC	SINGING		0	1		**2**						
	RHYTHM		0	1				**2**				
		0	10	20	30	40	50	60	70	80	90	100

Table 15: BDAE Subtest summary profile for BA (Goodglass and Kaplan, 1972).

Phonetic transcriptions

Word List A

	Orthographic	Repetition 1	Repetition 2
1.	a dart	ðə daɹt	ə daɹt
2.	a tip	ə tʰɪp	ə tʰɪp
3.	a leg	ə lɛg	ə lɛg
4.	a deer	ə diɹ	ə diɹ
5.	a chain	ə tʲen	ə tʲen
6.	a shark	ə ʃaɹk	ə ʃaɹk
7.	a key	ə kʰi:	ə kʲi:
8.	the dolls	ə d/dɔls	ðə (..) dɔlz
9.	a gear	ə (...) giɹ	ə giɹ
10.	a book	ə buk	ə buk
11.	a car	ə kʰaɹ	ə kʰaɹ
12.	a beak	ə bɹig̊	ə ʁ bik
13.	a knot	ə (..) nɔt	əndɔt ə (d) nɔt
14.	the dark	ðə daɹk	ðə daɹk
15.	a tick	ə tʰɪk	ə tʰɪk
16.	near	niɹ	niɹ
17.	sea	ðə si	ðə si
18.	she	ʃi	ʃi
19.	a tear	ə (d)tiɹ	ə tʰiɹ
20.	the sun	ðə sʌn	ðə sʌn
21.	a mouse	ə mɑʊs	ə mɑʊsʲ
22.	a cheer	ə tʃiɹ	ðə ʃ tʃiɹ
23.	a fish	ə ʃfɪʃ	ə fɪʃ
24.	a zoo	ə z̥u	ðə zu
25.	a sheep	ə ʃipᵊ	ə ʃipʰ
26.	a brush	ə bɹʌʃ	ə bɹʌʃ
27.	a leer	ə: liɹ	ə liɹ
28.	a seed	ə s̠i:d	ə (.) sid
29.	a shop	ə sʃɔp	ə ʃɔp
30.	a racer	ə ɹes̬ɜ:	ə ɹesɜɹ
31.	a leaf	ə li:f	ə lif

Table 16: Phonetic transcription of word list A produced by BA.

Word List B

	Orthographic	Repetition 1	Repetition 2
1.	a cocktail	ə kʰɔtʰkel tʰɔt˺tel	ə (.) kʰɔtʰkel
2.	a kitkat	ə kʰɪk˺takt	ə kʰɪktkaθ
3.	a clock	ə klɔk	ə klɔk
4.	a headlight	ə (..) hed.laɪt	ə hɛd. (..) laɪt
5.	a tractor	ətɹaktɔ:	ə tɹaktə
6.	a weekday	ə wik.de	ə wi:kde
7.	a tickling	ə tʰikliŋ	ə tɪklɪŋ
8.	a deckchair	ə d̥ɛktɛə	ə d̥ɛkteɹ
9.	a witchcraft	ðə (.) wɪtʃ.kɹaft	ðə w̯ɢɪtʃkɹaɪftʰ
10.	a bookshop	ə (.) bʌksʃɔp	ə bʌkʃɔp
11.	a star	ə staɹ	ə staɹ
12.	a box	ə bɔksʲ	ə bɔksʲ
13.	the hats	ðə hatsʲ	ðə hatz
14.	a squashkit	ə skwɔskɪt	ə skwɔtkɪtʰ
15.	a skirt	ə skeɹt	ə stɜɹt
16.	a catkin	ə katʰkɪn	ə katkɪn

Table 17: Phonetic transcription of word list B produced by BA.

CR (Broca's aphasic without AOS)

Boston Diagnostic Aphasia Examination

Conversational And Expository Speech

CR	eh _ _ em _ _ woman
	eh _ [s] _ dishes
SLT	good
CR	em [kɑf] over (referring to sink)
SLT	OK
CR	children _ girl _ boy
	cookie jar
	falling over _ er
SLT	OK, what are these two actually doing?
CR	em _ cookie jar
SLT	what are they doing with it though?
CR	em _ em _ er _
	eh stealing?
SLT	OK, good. They're stealing
CR	em _ huh
SLT	stealing the ?
CR	cookie
	aye
SLT	yeah. What exactly is happening here?
CR	eh _ [gaɪ] _ go _ um _ up _
	go em over
SLT	OK. What is going over?
CR	[gɒtə] _ water
SLT	Why is it overflowing?
CR	em
	yes er
	[wə] over goes flows
SLT	What's she done to make it overflow?
CR	cup _ em (gestures tap)
SLT	the?
CR	er tap
SLT	good
CR	em _ eh _ over [gəl] overfill
SLT	So she's left the tap, she's left it
CR	[daʊnd dɒn]
SLT	Turned on, yes, good. She's drying the dishes, but what do you think she's thinking about?

CR em _ eh _ [wən] er

[wɪn] em

ah day dreaming

dreaming

SLT good. I think she must be, yes.

SEVERITY RATING:	2
AUDITORY COMPREHENSION	Very few problems. Some difficulties with longer phrases of complex ideational material.
ORAL EXPRESSION	Verbal and non verbal oral agility movements were slow and often deteriorated across repetitions with assimilation of some sounds, e.g. “huckleberry” → [bʌkəlbeɹɪ:] Difficulty reciting months of the year and the alphabet, days of the week and counting were easier. Able to repeat all words but only one high probability phrase. Persistent literal paraphasia during this section. Articulatory difficulties, especially coordination and sequencing of movements affected oral reading and visual confrontation naming.
UNDERSTANDING WRITTEN LANGUAGE	Broke down at the sentence level where he was unable to extract meaning.
WRITING	Legible with non preferred hand. Cursive writing impaired. Able to recall all numbers through 21 and most of the letters of the alphabet. Single letters, numbers and primary words spelt to dictation were error free. Less familiar words were spelt incorrectly during written word finding tasks. Able to write a few sentences consisting of nouns and verbs.

Table 18: Summary of BDAE for CR.

BDAE Rating Scale Profile of Speech Characteristics

SEVERITY RATING	**2**		
MELODIC LINE	1 2 3 4 5 6 7 absent	Limited to short phrases and stereotypes	Runs through entire sentence
PHRASE LENGTH	1 word	4 words	7 words
ARTICULATORY AGILITY	Always impaired or impossible	Normal only in familiar words and phrases	Never impaired
GRAMMATICAL FORM	None available	Limited to simple declaratives and stereotypes	Normal range
PARAPHASIA IN RUNNING SPEECH	Present in every utterance	Once per minute of conversation	absent
REPETITION	0 0 1 2 4 6 8		
WORD FINDING	Fluent without information	Information proportional to fluency	Speech exclusively content words
AUDITORY COMPREHENSION	1 15 30 45 60 75 90		
VOLUME	Hypophonic	**Normal**	Loud
VOICE	Whisper	Hoarse	**Normal**
RATE	Slow	Normal	Rapid

Table 19: BDAE Rating Scale Profile of Speech Characteristics for CR (Goodglass and Kaplan, 1972).

BDAE Subtest summary profile

	PERCENTILES	0	10	20		30	40	50		60		70		80	90	100
SEVERITY RATING			0	1						**2**				3	4	5
FLUENCY	ARTICULATORY RATING		1	**2**		4	5	6				7				
	PHRASE LENGTH			1	**2**	3	4	5		6		7				
	MELODIC LINE		1	2		**4**		6		7						
	VERBAL AGILITY		0	2		5	**6**	8		9		11		13	14	
AUDITORY COMPREHENSION	WORD DISCRIMINATION	0	15	25		37	46	53		60		64		67	**70**	72
	BODY-PART IDENTIFICATION	0	1	5		10	13	15		16		17		18	**19**	20
	COMMANDS	0	3	4		6	8	10		11		13		**14**	15	
	COMPLEX IDEATIONAL MATERIAL		0	2		3	4	5		6		**8**		9	11	12
NAMING	RESPONSIVE NAMING			0		1	5	10		15		20		24	27	**30**
	CONFRONTATION NAMING		0	9		28	43	60		72		84		94	105	**114**
	ANIMAL NAMING					0	1	2		3		4		6	**9**	23
ORAL READING	WORD READING			0		1	3	7		15		**21**		26	30	
	ORAL SENTENCE READING						0	**1**		2		4		7	9	10
REPETITION	REPETITION OF WORDS		0	2	**4**	5	7	8				9			10	
	HIGH-PROBABILITY			0		**1**		2		4		5		7	8	
	LOW-PROBABILITY						**0**	1				2		4	6	8
PARAPHASIA	NEOLOGISTIC	40	16	9		4	**2**	1				0				
	LITERAL	47	17	12		**9**	6	5		3		2		1	0	
	VERBAL	40	23	18		15	12	**9**		7		4		3	1	0
	EXTENDED	75	12	5		3	1	**0**								
AUTOMATIC SPEECH	AUTOMATIZED SEQUENCES		0	1		2	3	4	**5**	6		7			8	
	RECITING					0	**1**							2		
READING COMPREHENSION	SYMBOL DISCRIMINATION	0	2	5		7	8	9				**10**				
	WORD RECOGNITION	0	1	3		4	5	6		7				**8**		
	COMPREHENSION OF ORAL SPELLING					0	1			3		**4**		6	7	8
	WORD-PICTURE MATCHING		0	1		4	6	**8**		9				10		
	READING SENTENCES & PARAGRAPHS		0	1		2	3	**4**		5		6		7	8	10
WRITING	MECHANICS	1		2			3			**4**					5	
	SERIAL WRITING		0	7		18	25	30		33		40	**41**	43	46	47
	PRIMER-LEVEL DICTATION		0	1		4	6	9		11		13		14	**15**	
	SPELLING TO DICTATION						0	1		2		3		**5**	7	10
	WRITTEN CONFRONTATION NAMING					0	1	2		3		6		7	**9**	10
	SENTENCES TO DICTATION							0		1	**2**	3		6	8	12
	NARRATIVE WRITING		0	1				**2**						3	4	
MUSIC	SINGING		0	1			**2**									
	RHYTHM		0	**1**						2						
		0	10	20		30	40	50		60		70		80	90	100

Table 20: BDAE Subtest summary profile for CR (Goodglass and Kaplan, 1972).

Frenchay Dysarthria Profile

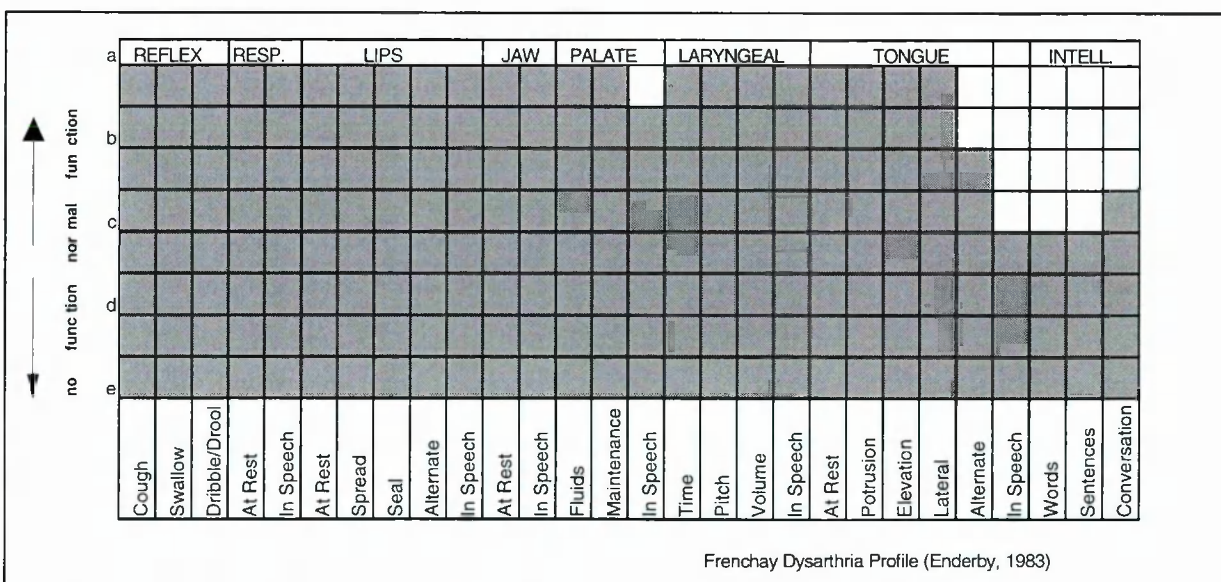


Figure 3: Frenchay Dysarthria Profile for CR (Enderby, 1983).

Phonetic transcriptions

Word List A

	Orthographic	Repetition 1	Repetition 2
1.	a dart	ðə faɹt	ʌ daɹt
2.	a tip	ʌ t^{h}ɪp	ʌ d̥ɪp
3.	a leg	ə lɛg̊	ʌ ʎɛd̚g
4.	a deer	ə diɹ	ʌ d^{j}iɹ
5.	a chain	ʌ tʃen	ʌ tʃen
6.	a shark	ʌ t^{h}ə ʃaɹk ʌ t͡ʃaɹk ʌ fɸaɹk	ʌ tʃaɹk
7.	a key	ʌ tʃi	ʌ fgi
8.	the dolls	ʌ dɔt	ðə dɔʌs
9.	a gear	ʌ giɹ	ʌg^{n}iɹ
10.	a book	ʌ buk	ʌ du buk
11.	a car	ʌ k^{h}aɹ	ʌ tʃaɹ
12.	a beak	ʌ bik	ʌ bik
13.	a knot	ʌ nɔt	ʌ s:bɔt ʌ nɔt
14.	the dark	ʌ daɹk	
15.	a tick	ʌ d͡gɪk	ʌ t̥ɪk
16.	near	d^{n}iɹ	ʌ d^{n}iɹ
17.	sea	ʌ si	ʌ tʃi
18.	she	ʌ s^{j}i	ʌ ʃi ʃi
19.	a tear	ʌ t̥iɹ	t^{j}iɹ
20.	the sun	ʌ sʌn	s:ə sʌn
21.	a mouse	ʌ mɑus	ʌ b^{n}aus
22.	a cheer	ʌ tʃiɹ	ʌ kʃiɹ
23.	a fish	ʌ ʃ:b̥ɪʃ	ʌ ʃpɪsʃ
24.	a zoo	ʌ s̬u	ʌ s̬u:
25.	a sheep	ʌ ʃip	ʌ s^{j}ip
26.	a brush	ʌ bɹʌʃ	ʌ bɹʌʃ
27.	a leer	ʌ liɹ	ʌ liɹ
28.	a seed	ʌ s^{j}id	ʌ s^{j}id
29.	a shop	ʌ s^{j}ɔp	ʌ ʃɔp
30.	a racer	ʌ sɹesɜɹ	ʌ s̆ɹesɜɹ
31.	a leaf	ʌ lif	ʌ lif

Table 21: Phonetic transcription of word list A produced by CR.

Word List B

	Orthographic	Repetition 1	Repetition 2
1.	a cocktail	ʌ d^{n}ɔtel	ʌ ɢɔk̚tel
2.	a kitkat	ʌ k^{h}ɪt̚d^{n}at	ʌ kat̚ ə k^{h}ɪt̚dat ʌ k^{h}ɪt̚kat
3.	a clock	ʌ wɔk̚ klɔk	ʌ klɔk
4.	a headlight	ʌ hɛd̚leq	ʌ (.) hɛdleʔ
5.	a tractor	ʌ gaktə	ʌ t^{h}ɪk̚ d̦aktə
6.	a weekday	ʌ b^{n}ikge	ʌ bik̚be
7.	a tickling	ʌ t^{h}ɪkə̆lɪŋ	ʌ ɸɪkəlɪŋ
8.	a deckchair	ʌ d͡gɛktʃeɹ	ʌ d^{n}ɛktʃɛə
9.	a witchcraft	ʌ dɹɪpʃaf	ðə kɹɪpkɹaft swɪʃk̦aft
10.	a bookshop	ʌ bukʃɔp	ʌ b^{n}uksbɔp ʌbuks^{n}ɔp
11.	a star	s: staɹ	ʌ s:aɹ
12.	a box	ʌ β͡bɔks	ʌbɔks
13.	the hats	ʌ hat	ʌ hat
14.	a squashkit	ʌ ʃɔskɪt	ʌ gwɔskɪt
15.	a skirt	ʌ ʃɜɹt	ʌ ʃɜɹt
16.	a catkin	ʌ kat̚tɪn	ʌ kat̚kɪn

Table 22: Phonetic transcription of word list B produced by CR.

Phonetic transcriptions

Repetitions

"deer"	
Repetition	Phonetic Transcription
1.	ə diɾ
2.	ə d̥iɾ
3.	ə diɾ
4.	ə jiɾ
5.	ə diɾ
6.	ə diɾ
7.	ə diɾ
8.	ə djiɾ
9.	ə diɾ
10.	ə diɾ

"clock"	
Repetition	Phonetic Transcription
1.	ə tʷɹɔk
2.	ə klɔk
3.	ə k̬lɔk
4.	ə klɔk
5.	ə klɔk
6.	ə klɔk
7.	ə klɔk
8.	ə klɔk
9.	ə kʰəlɔk
10.	ə kʰəlɔk

"kitkat"	
Repetition	Phonetic Transcription
1.	ə kʰɪt̚kat
2.	ə kʰɪʔkat
3.	ə kʰɪʔkat
4.	ə kʰɪʔkat
5.	ə kʰɪʔkat
6.	ə kʰɪt̚kat
7.	ə kʰɪt̚kat
8.	ə kʰɪt̚kat
9.	ə kʰɪt̚kat
10.	ə kʰɪtkat

Table 23: Phonetic transcription of the repetition task produced by CR.

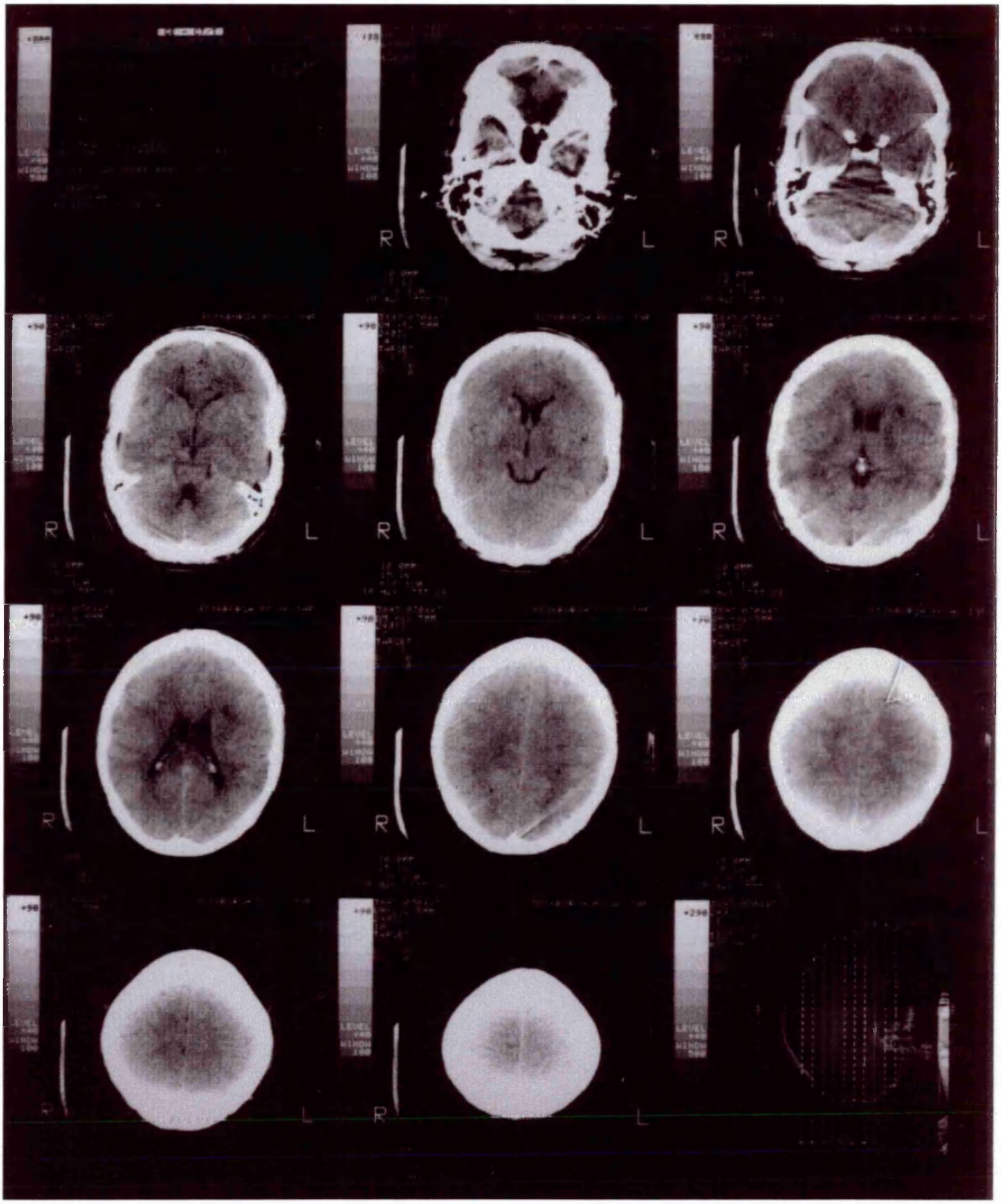


Figure 4: CT scan for CR.

JM (Broca's aphasic without AOS)

Boston Diagnostic Aphasia Examination

Conversational And Expository Speech

JM	woman
	washing dishes
	guy _ boy _ cookie jar
	[bə ɪm i] girl
	eh water er (laughs) bill _ spill
	er dress
	er [ku:l]
SLT	close, it's a st
JM	stool
SLT	What do you think the mother is doing apart from washing the dishes?
JM	washing er
	ah (unintelligible)ing
SLT	dreaming?
JM	ah dreaming
SLT	And I don't think she's noticed
JM	these (points to boy and girl)
SLT	That's right, she hasn't noticed those two
JM	noticed those two

SEVERITY RATING	1
AUDITORY COMPREHENSION	Good auditory comprehension. Occasional left / right confusion when asked to identify body parts. Some confusion with complex ideational material.
ORAL EXPRESSION	Able to perform the non-verbal oral agility tasks easily and at speed, but had great difficulty with the verbal component demonstrating much groping, substitution of phonemes and a decreased rate. Performance was suggestive of apraxia of speech in the absence of any oral apraxia Automatic speech was impaired. Only able to recite the days of the week. All subtests in the Oral Expression section highlighted extreme articulatory impairment.
UNDERSTANDING WRITTEN LANGUAGE	Some difficulty with phonetic association and reading sentences and paragraphs.
WRITING	Writes legibly with non preferred hand. Difficulty with all sections except transcription.

Table 24: Summary of BDAE for JM.

BDAE Rating Scale Profile of Speech Characteristics

SEVERITY RATING	2		
MELODIC LINE	1 2 3 4 5 6 7 absent — Limited to short phrases and stereotypes — Runs through entire sentence		
PHRASE LENGTH	1 word — 4 words — 7 words		
ARTICULATORY AGILITY	Always impaired or impossible — Normal only in familiar words and phrases — Never impaired		
GRAMMATICAL FORM	None available — Limited to simple declaratives and stereotypes — Normal range		
PARAPHASIA IN RUNNING SPEECH	Present in every utterance — Once per minute of conversation — absent		
REPETITION	0 0 1 2 4 6 8		
WORD FINDING	Fluent without information — Information proportional to fluency — Speech exclusively content words		
AUDITORY COMPREHENSION	1 15 30 45 60 75 90		
VOLUME	Hypophonic	**Normal**	Loud
VOICE	Whisper	Hoarse	**Normal**
RATE	Slow	**Normal**	Rapid

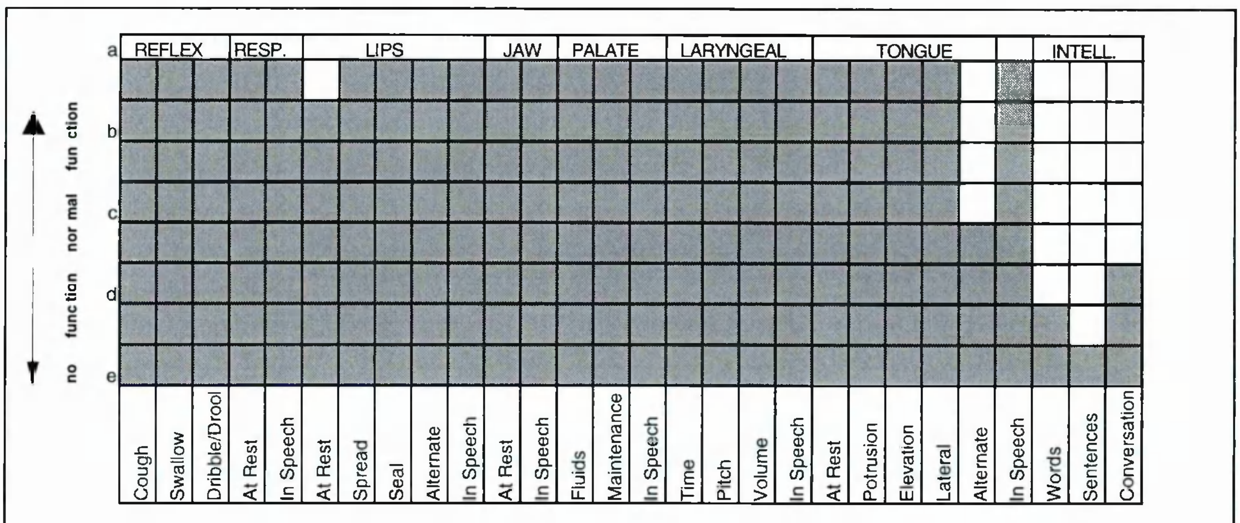
Table 25: BDAE Rating Scale Profile of Speech Characteristics for JM (Goodglass and Kaplan, 1972).

BDAE Subtest summary profile

	PERCENTILES	0	10	20		30	40	50	60		70		80		90	100
SEVERITY RATING			0	1					**2**				3		4	5
FLUENCY	ARTICULATORY RATING		1	2	**3**	4	5	6			7					
	PHRASE LENGTH			1		3	**4**	5	6		7					
	MELODIC LINE		1	2		**4**		6	7							
	VERBAL AGILITY		0	2		5	**6**	8	9		11		13		14	
AUDITORY COMPREHENSION	WORD DISCRIMINATION	0	15	25		37	46	53	60		64		**67**		70	72
	BODY-PART IDENTIFICATION	0	1	5		10	13	15	16	**16.5**	17		18			20
	COMMANDS	0	3	4		6	8	10	11	**12**	13		14		15	
	COMPLEX IDEATIONAL MATERIAL		0	2		3	4	5	6		**8**		9		11	12
NAMING	RESPONSIVE NAMING			0		1	5	10	15		20		24		27	**30**
	CONFRONTATION NAMING		0	9		28	43	60	72		84		94	**97**	105	114
	ANIMAL NAMING					0	1	2	3		4		6	**7**	9	23
ORAL READING	WORD READING			0		1	3	7	15		21	**25**	26		30	
	ORAL SENTENCE READING						0	1	2		**4**		7		9	10
REPETITION	REPETITION OF WORDS		0	2		5	7	8			9				**10**	
	HIGH-PROBABILITY			0		1		2	4		5	**6**	7		8	
	LOW-PROBABILITY						0	1			2		4		6	**8**
PARAPHASIA	NEOLOGISTIC	40	16	9		4	2	1			**0**					
	LITERAL	47	17	12		9	6	5	3		**2**		1		0	
	VERBAL	40	23	18		15	12	9	7		4		3		1	**0**
	EXTENDED	75	12	5		3	1	**0**								
AUTOMATIC SPEECH	AUTOMATIZED SEQUENCES		0	1		2	3	4	6		**7**				8	
	RECITING					0	1						**2**			
READING COMPREHENSION	SYMBOL DISCRIMINATION	0	2	5		7	8	9			**10**					
	WORD RECOGNITION	0	1	3		4	5	**6**	7				8			
	COMPREHENSION OF ORAL SPELLING					0	1		**3**		4		6		7	8
	WORD-PICTURE MATCHING		0	1		4	6	8	**9**				10			
	READING SENTENCES & PARAGRAPHS		0	1		2	3	**4**	5		6		7		8	10
WRITING	MECHANICS	1		2			**3**		4						5	
	SERIAL WRITING		0	7		18	25	30	33	**37**	40		43		46	47
	PRIMER-LEVEL DICTATION		0	1		4	6	9	11		**13**		14		15	
	SPELLING TO DICTATION						0	**1**	2		3		5		7	10
	WRITTEN CONFRONTATION NAMING					0	1	2	3		6		**7**		9	10
	SENTENCES TO DICTATION							0	1		**3**		6		8	12
	NARRATIVE WRITING		0	1				**2**					3		4	
MUSIC	SINGING		0	1			**2**									
	RHYTHM		0	**1**					2							
		0	10	20		30	40	50	60		70		80		90	100

Table 26: BDAE Subtest summary profile for JM (Goodglass and Kaplan, 1972)

Frenchay Dysarthria Profile



Frenchay Dysarthria Profile (Enderby, 1983)

Figure 5: Frenchay Dysarthria Profile for JM (Enderby, 1983).

Phonetic transcriptions

Word List A

	Orthographic	Repetition 1	Repetition 2
1.	a dart	ʌ daɹt	də daɹt
2.	a tip	ə tʃɪp ə tʰɪp	ə tʰɪp
3.	a leg	a lɛg̊	ə lɛg
4.	a deer	ʌ diɾ	ə diɾ
5.	a chain	a tʃen	ə tʃen
6.	a shark	a ʃaɹk	ɹe ə nə ə ʃaɹk
7.	a key	ə kʰi	ə kʰi
8.	the dolls	ðə dɔl	ʌ dɔl
9.	a gear	ʌ giɹɾ	ʌ g̊iɾ
10.	a book	a buk	ə buk
11.	a car	ʌ k̠ʰaɾ	ə k̠ʰaɾ
12.	a beak	ə bik	ə biˈk
13.	a knot	aɰ nɔt	ə̃ nɔt
14.	the dark	ðə daɹk	ə daɹk
15.	a tick	ə tʰɪk	ə tʰɪk
16.	near	niɾ	ə niɾ
17.	sea	ə si	ə si
18.	she	ə ʃi	ə ʃi
19.	a tear	ə tʰiɾ	ə tʰiɾ
20.	the sun	ə sʌn	ə sən
21.	a mouse	ə̃ maʊ̃s	ə maus
22.	a cheer	ə tʃiɹz	ə tʃiɹ
23.	a fish	ə fɪʃ	ə fɪʃ
24.	a zoo	ə zu	ə zu:
25.	a sheep	ə ʃip	ə ʃip
26.	a brush	ə bɹʌʃ	ə bʷʌʃ
27.	a leer	a liɾ	ə liɾ
28.	a seed	a: sid	ə sid
29.	a shop	ə ʃɔp	ə ʃip ə ʃɔp
30.	a racer	ə ɹesɜɾ	ə ɹesə
31.	a leaf	ə lif	ə lif

Table 27: Phonetic transcription of word list A produced by JM.

Word List B

	Orthographic	Repetition 1	Repetition 2
1.	a cocktail	ə kʰɔ̃k̚tɛ̃l	k̠ʰɔɽdel
2.	a kitkat	ə kʰɪ̃dnat	ə kʰɪt̚dǎt
3.	a clock	ə qɔ̃k	k̥lɔk
4.	a headlight	hɛdlaɪt	hɛslaɪz ə hɛdlaɪt
5.	a tractor	ə twaktə	ə ɯakɜɹ
6.	a weekday	ə wi:kge	wi:k̚gez
7.	a tickling	ə tʰɪ̃ktlɪ̃n	ə tʰɪkəlɪŋ
8.	a deckchair	ə dʲɛkweə	ə dɹɛkfeɜ ə dɹɛkfeɜ
9.	a witchcraft	ə vɪʃaf	ɔ wɪʃa:f
10.	a bookshop	ə bukʃɔp̚	a bukʃɔp
11.	a star	ə s̃taɹ	ʌ sa:
12.	a box	ə bɔqs	
13.	the hats	hat	ʌ hats
14.	a squashkit	ə swɔsɪt	ə sβwɔskɪt
15.	a skirt	ə t̃sɜɹt	ə stɜɹt
16.	a catkin	ə katdɪ̃n	ə kat̚dɪn

Table 28: Phonetic transcription of word list B produced by JM.

Phonetic transcriptions

Repetitions

"deer"	
Repetition	Phonetic Transcription
1.	ə diɾ
2.	ə diɾ
3.	ə diɾ
4.	ə diɾ
5.	ə diɾ
6.	ə diɾ
7.	ə diɾ
8.	ə diɾ
9.	ə diɹ:
10.	ə diɾ

"clock"	
Repetition	Phonetic Transcription
1.	ə kʰɔk
2.	ə g̊ɔk
3.	ə kʰɔk
4.	ə kʰɔk
5.	ə klɔk
6.	ə gɔk
7.	ə k̬lɔk
8.	ə k̬lɔk
9.	ə k̬lɔk
10.	ə k̬lɔk

"kitkat"	
Repetition	Phonetic Transcription
1.	ə kʰɪt̚dat
2.	ə kʰɪt̚dat
3.	ə kʰɪt̚dat
4.	ə kʰɪd̚gat
5.	ə kʰɪt̚dat
6.	ə kʰɪdnat
7.	ə kʰɪdnat
8.	ə kʰɪd̚tat
9.	ə kʰɪd̚nat
10.	ə kʰɪdnat

Table 29: Phonetic transcription of the repetition task produced by JM.

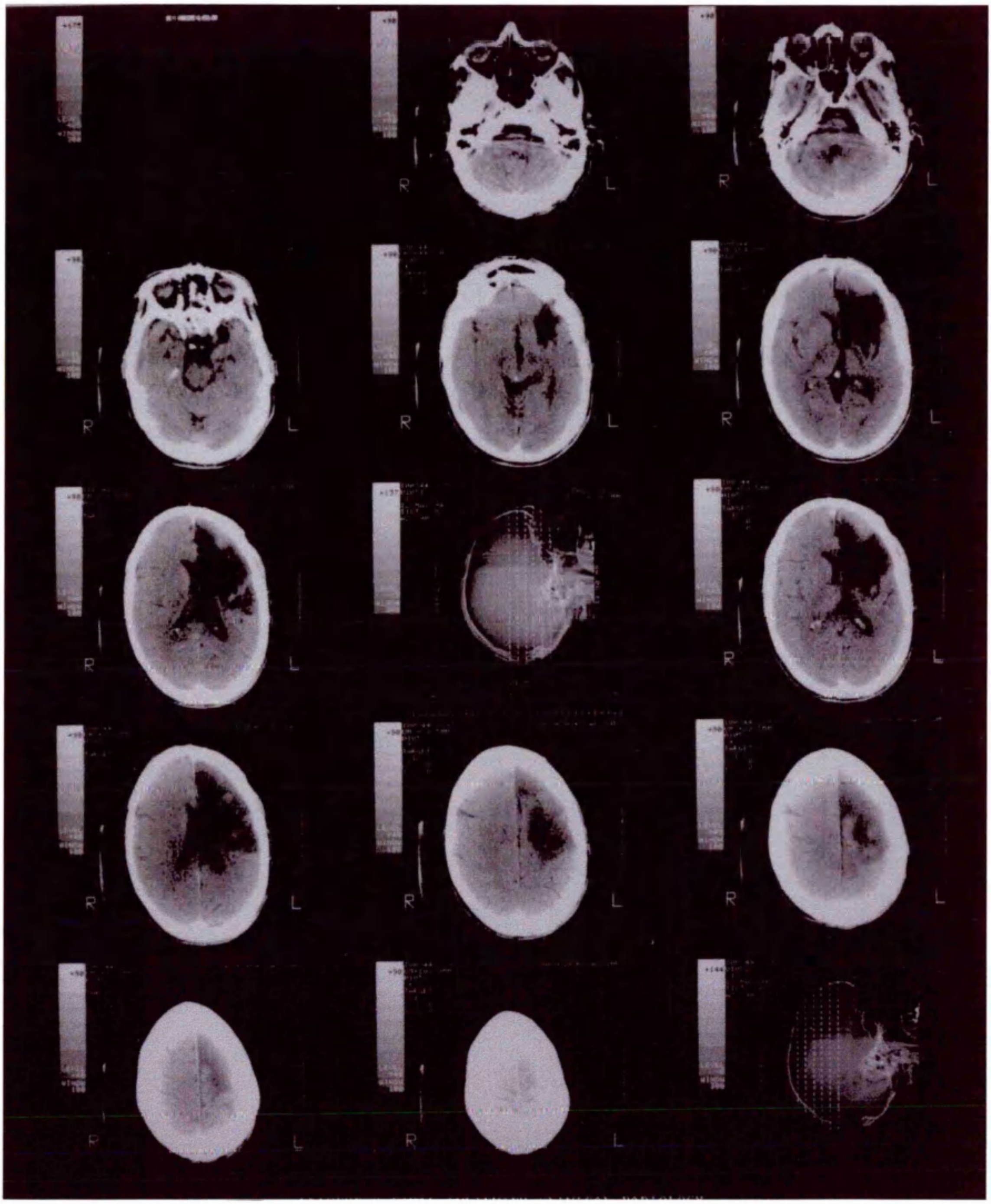


Figure 6: CT scan for JM.

IE (conduction aphasic)

Boston Diagnostic Aphasia Examination

Conversational And Expository Speech

IE	there's a girl a man uh a girl er a boy
	lock in a _ _ _
	er fell down
	and a boy
	an is rushing
	kitchen er tap
	that's all
SLT	who's this here?
IE	that's the mother _ mother
SLT	what's she doing?
IE	turn around
SLT	what's she actually doing
IE	er tap er long away South Africa
	lost
SLT	she's far away you mean?
IE	yes
	tap running away from um tap er water
SLT	what are the children doing?
IE	there [ə] fell down
	a boy and er "come on"
	"look"
	there's a girl
	"careful"
SLT	why is the boy on the stool?
IE	cookie jar er
	I don't know
	fell down or er er "careful"
	this gel and er I reach up
	tin
	fall down
	that's all
	day dreaming

SEVERITY RATING	2
AUDITORY COMPREHENSION	Scored well throughout this section indicating good auditory comprehension skills. Experienced difficulty with longer more complex commands, e.g. "Tap *each shoulder twice* with *two fingers* keeping your *eyes shut*."
ORAL EXPRESSION	Able to repeat rapid non verbal movements but experienced great difficulty repeating words at speed. These were produced at a decreased rate with paraphasic errors. Unable to complete automatized sequences except for days of the week. Difficulties reciting, singing and copying rhythms. Difficulties repeating both low and high probability phrases. Lexical retrieval problems highlighted during naming subtests. Often an large response lag time to a question or request and circumlocution was frequent.
UNDERSTANDING WRITTEN LANGUAGE	Understanding symbols and words was relatively error free. Great difficulty understanding sentences and paragraphs achieving a score at the 50th %tile.
WRITING	Non preferred hand, legible but not judged to be at the pre-morbid level. All tasks except transcription presented problems. Phoneme to grapheme conversion was difficult.

Table 30: Summary of BDAE for IE.

BDAE Rating Scale Profile of Speech Characteristics

SEVERITY RATING	2		
MELODIC LINE	1 2 3 4 5 6 7		
	absent	Limited to short phrases and stereotypes	Runs through entire sentence
PHRASE LENGTH	1 word	4 words	7 words
ARTICULATORY AGILITY	Always impaired or impossible	Normal only in familiar words and phrases	Never impaired
GRAMMATICAL FORM	None available	Limited to simple declaratives and stereotypes	Normal range
PARAPHASIA IN RUNNING SPEECH	Present in every utterance	Once per minute of conversation	absent
REPETITION	0 0 1 2 4 6 8		
WORD FINDING	Fluent without information	Information proportional to fluency	Speech exclusively content words
AUDITORY COMPREHENSION	1 15 30 45 60 75 90		
VOLUME	Hypophonic	**Normal**	Loud
VOICE	Whisper	Hoarse	**Normal**
RATE	Slow	**Normal**	Rapid

Table 31: BDAE Rating Scale Profile of Speech Characteristics for IE (Goodglass and Kaplan, 1972).

BDAE Subtest summary profile

	PERCENTILES	0		10	20		30		40		50		60		70	80		90	100
SEVERITY RATING				0	1								**2**			3		4	5
FLUENCY	ARTICULATORY RATING			1	2		**4**		5		6				7				
	PHRASE LENGTH				1		3		4		5		**6**		7				
	MELODIC LINE			1	2		4				**6**		7						
	VERBAL AGILITY			0	2	**3**	5		6		8		9		11	13		14	
AUDITORY COMPREHENSION	WORD DISCRIMINATION	0		15	25		37		46		53		60		64	67	**69**	70	72
	BODY-PART IDENTIFICATION	0		1	5		10		13		15		16		17	**18**			20
	COMMANDS	0		3	4		6		8		**10**		11		13	14		15	
	COMPLEX IDEATIONAL MATERIAL			0	2		3		4		5		6		8	9	**10**	11	12
NAMING	RESPONSIVE NAMING				0		1		5		10	**13**	15		20	24		27	30
	CONFRONTATION NAMING			0	9		28		43	**57**	60		72		84	94		105	114
	ANIMAL NAMING						0		1		2		3		4	6	**8**	9	23
ORAL READING	WORD READING				0		1		3		7		**15**		21	26		30	
	ORAL SENTENCE READING								0		1		2	**3**	4	7		9	10
REPETITION	REPETITION OF WORDS			0	2		5		**7**		8				9			10	
	HIGH-PROBABILITY				0		**1**				2		4		5	7		8	
	LOW-PROBABILITY								**0**		1				2	4		6	8
PARAPHASIA	NEOLOGISTIC	40		16	9		4	**3**	2		1				0				
	LITERAL	47	**38**	17	12		9		6		5		3		2	1		0	
	VERBAL	40		23	18		15		12		9		7		4	3		1	**0**
	EXTENDED	75		12	5		3		1		**0**								
AUTOMATIC SPEECH	AUTOMATIZED SEQUENCES			0	1		2		3		**4**		6		7			8	
	RECITING						0		**1**							2			
READING COMPREHENSION	SYMBOL DISCRIMINATION	0		2	5		7		8		9				**10**				
	WORD RECOGNITION	0		1	3		4		5		6		7			**8**			
	COMPREHENSION OF ORAL SPELLING						0		1				3		**4**	6		7	8
	WORD-PICTURE MATCHING			0	1		4		6		8		9			**10**			
	READING SENTENCES & PARAGRAPHS			0	1		2		3		**4**		5		6	7		8	10
WRITING	MECHANICS	1			2				3				**4**					5	
	SERIAL WRITING			0	7		18		25	**28**	30		33		40	43		46	47
	PRIMER-LEVEL DICTATION			**0**	1		4		6		9		11		13	14		15	
	SPELLING TO DICTATION								**0**		1		2		3	5		7	10
	WRITTEN CONFRONTATION NAMING						**0**		1		2		3		6	7		9	10
	SENTENCES TO DICTATION										0		1		3	6		8	12
	NARRATIVE WRITING			0	1						**2**					3		4	
MUSIC	SINGING			0	1				**2**										
	RHYTHM			0	1								**2**						
		0		10	20		30		40		50		60		70	80		90	100

Table 32: BDAE Subtest summary profile for IE (Goodglass and Kaplan, 1972).

Frenchay Dysarthria Profile

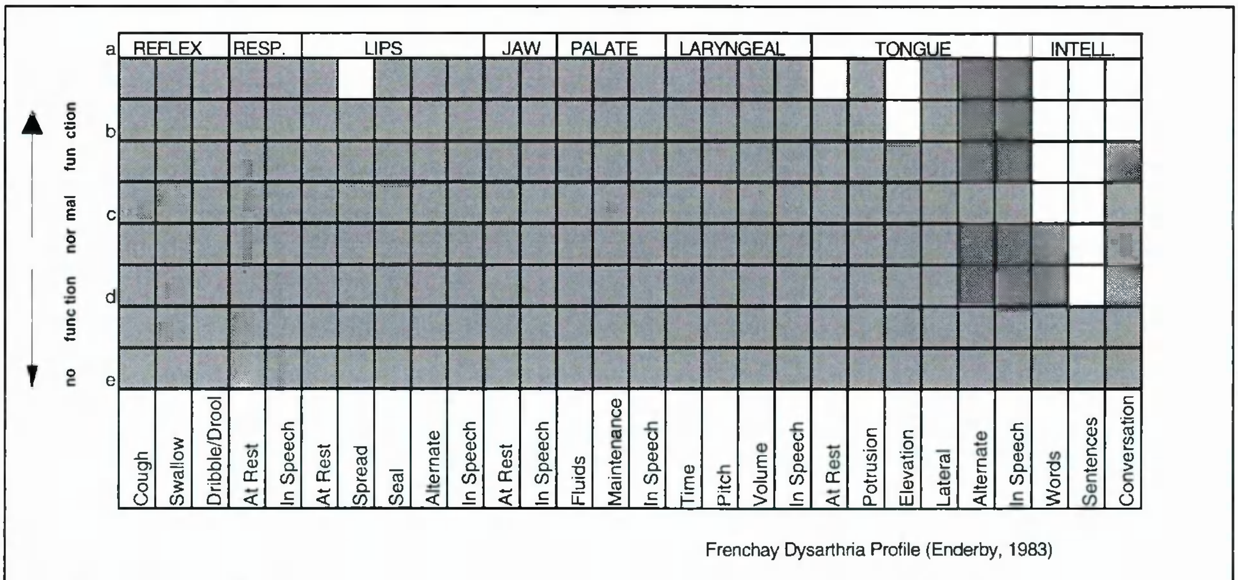


Figure 7: Frenchay Dysarthria Profile for IE (Enderby, 1983).

Phonetic transcriptions

Word List A

	Orthographic	Repetition 1	Repetition 2
1.	a dart	ə dɑ:t	də dɑ:ɹt
2.	a tip	ə tʰɪp	ə tʰɪp
3.	a leg	ə lɛ͡gd	ə lɛg̊
4.	a deer	ə diɹ	ə di:ə
5.	a chain	ən tʃeɪn	ə tʲenz
6.	a shark	ə t͡tʃɑ:t	ə sʃɑ:ɹt
7.	a key	ə tʰi:	ə tʰi
8.	the dolls	ðes dɔ:ɹz	ðe dɔ:ɹz dɔ:ɹz dɔlz
9.	a gear	ə diə	ðə tʃiəz tʃiəz tʃiəz
10.	a book	ə buʌt	ðə buk
11.	a car	ə kʰɑɹ	ə kʰ/kʰ/kʰɑɹz
12.	a beak	ə bik	ə (d) bit
13.	a knot	ə n:ɒt	ə (d) nɒt
14.	the dark	ðə dɔɑɹt	ðə dɑɹt
15.	a tick	ə kʰɪt	də t͡ʃit tʰi:t
16.	near	niəlɛ	niə
17.	sea	ðdə si:	də si
18.	she	si:	sʲi
19.	a tear	ə tʰiə	ðə tʃiə
20.	the sun	ðə sʌn	ðə sʌn
21.	a mouse	ðed mɑus	e mɑus
22.	a cheer	də tʃiəɹ	tʲə tʃiə
23.	a fish	də fɪs	ðə fɪsʲ
24.	a zoo	də z̥u:	də (d) zu
25.	a sheep	də s/s/si:p	də sʃip
26.	a brush	də bɹʌs	də bɹʌsʃ
27.	a leer	də d͡lliə	ðə liə
28.	a seed	də sid	ðə sind
29.	a shop	də sʃɒp	də sʲɒp
30.	a racer	ðə ɹeɪsəɹ	də ɹeɪsʲɜɹ
31.	a leaf	ðə li:f	də lif

Table 33: Phonetic transcription of word list A produced by IE.

Word List B

	Orthographic	Repetition 1	Repetition 2
1.	a cocktail	də kʰɔk͡tkeɪl	də kʰɒt˺tɛl
2.	a kitkat	ə tʰɪk˺tækt	də kʰætti:t
3.	a clock	ə klɒk	ðdə klɒk
4.	a headlight	də heldleɪt	də hɛdlaɪt
5.	a tractor	də kɹæktə	də kɹæk˺tɔ:
6.	a weekday	də wi:kdend end	də wi:tdeɪz deɪ
7.	a tickling	ðə tʰɪtəɬɪn tʰɪtəɬɪn	tʰɪtəɬɪn
8.	a deckchair	də tʰet˺tʃɛə	ə tʰɛdtʲɛə
9.	a witchcraft	wɪstɹaf	də wɪsʲtɹæf
10.	a bookshop	dəl bɒʔ buksɒp	də buksɒp
11.	a star	də stɹɑð s:tɑ:d̥	ðə stɹɑ:
12.	a box	dəd˺ bɔ:z bɒks	də bɒ̃ks
13.	the hats	dəz hæt hæt˺s	ðis hæt hæts
14.	a squashkit	də skwɒsti:t	də skwɒtkiˈt
15.	a skirt	stɜ:ɹt	də skɜəlt
16.	a catkin	də kætkɪn	də kʰætkɪn

Table 34: Phonetic transcription of word list B produced by IE.

Phonetic transcriptions

Repetitions

"deer"	
Repetition	Phonetic Transcription
1.	ə diɾ
2.	ə g͡diə
3.	ə də ə diə
4.	ə gə ə diə
5.	ə diə
6.	ə diɹ
7.	ə diɹ
8.	ə diɹ
9.	ə diɹ
10.	ə diɹ

"clock"	
Repetition	Phonetic Transcription
1.	ə klɔk
2.	ə klɔk
3.	ə klɔk
4.	ə g̊lɔk
5.	ə klɔk
6.	ə klɔk
7.	ə klɔk
8.	ə klɔk
9.	ə klɔk
10.	ə klɔk

"kitkat"	
Repetition	Phonetic Transcription
1.	ə tʰɪdkæt
2.	ə tʰɪdkæt
3.	ə tʰɪtkæt
4.	ə tʰɪtktæt
5.	ə tʰɪtkæt
6.	ə kʰɪdkæt
7.	ə tʰɪtkæt
8.	ə kʰætʰtɪt
9.	ə tʰɪtkæt
10.	ə tʰɪtkæt

Table 35: Phonetic transcription of the repetition task produced by IE.

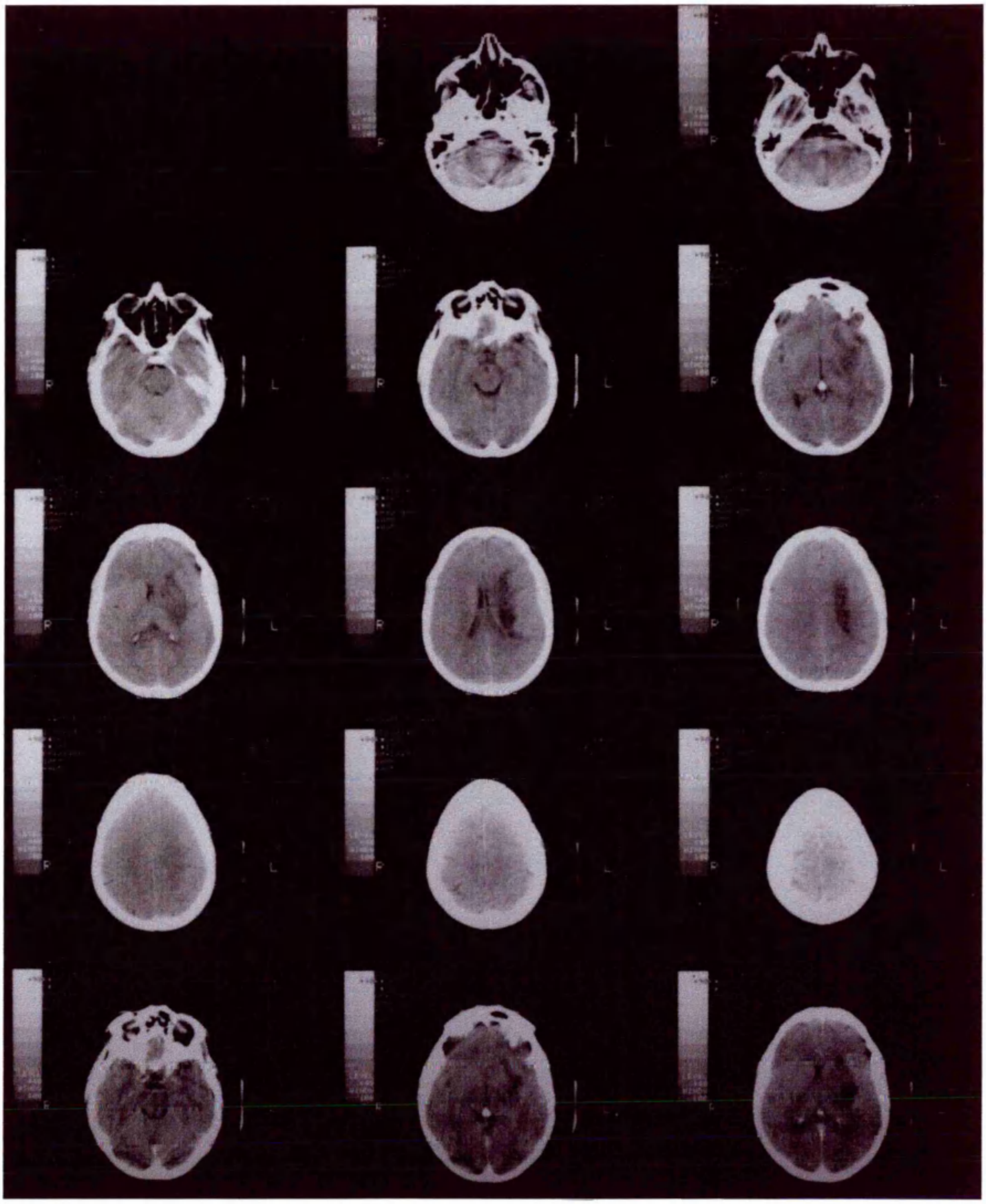


Figure 8: CT scan for IE.

PW (conduction aphasic)

Boston Diagnostic Aphasia Examination

Conversational And Expository Speech

PW: Well er

wee boy standing on a stool

[ɹi:] reach for a er _ _ _ a cookie

is _ _ he's fallen

wee girl [sændɪ] up

er no (unintelligible) where [æn]

reach by _ _ _ no _ _ _ each girl she's [gæ kæ] canna

she's standing at the sink waiting for _ _

SLT What's she doing here?

PW [blə ə bə] plate

and she's [gə ə wɪ] _ _ _ and [sə] overflows

SLT Anything else?

PW no _ is sink overflows

just (unintelligible)

the sink _ _ _ an [fɪʃɛz fɪʃɛz fɪʃɛz]

SLT dishes?

PW dishes

SEVERITY RATING	2
AUDITORY COMPREHENSION	Identified most of the items in this section. Most difficulty with shapes, letters and right / left discrimination. All commands successfully executed. Greatest difficulty was with complex ideational material with 4 out of a possible 12 scored.
ORAL EXPRESSION	Able to perform all non-verbal and verbal agility tasks although some were slow and hesitant. Automatized speech and repetition of words and phrases also successfully completed for the most part although the more complex low probability phrases could not be retained in STM. Most difficulty with Visual Confrontation Naming and Animal Naming. Needed frequent prompting during Visual Confrontation Naming and demonstrated articulatory groping of initial consonants felt in part to be due to word finding difficulties. Frequent phonemic paraphasic errors and repetition of initial consonants were noted throughout this section.
UNDERSTANDING WRITTEN LANGUAGE	Difficulty matching letters and words and comprehending oral spelling. Recognition of words presented orally and matching pictures to words were only mildly impaired. Unable to extract meaning from longer sentences and paragraphs.
WRITING	Writing was with the non preferred hand, legible but not judged to be of pre-morbid standard. Successfully completed serial writing, primer level dictation and sentence transcription. Unable to complete sections requiring phoneme to grapheme conversion, or when she was required to access lexical items from pictures.

Table 36: Summary of BDAE for PW.

BDAE Rating Scale Profile of Speech Characteristics

SEVERITY RATING	**2**		
MELODIC LINE	1 2 3 4 5 6 7 absent — Limited to short phrases and stereotypes — Runs through entire sentence		
PHRASE LENGTH	1 word — 4 words — 7 words		
ARTICULATORY AGILITY	Always impaired or impossible — Normal only in familiar words and phrases — Never impaired		
GRAMMATICAL FORM	None available — Limited to simple declaratives and stereotypes — Normal range		
PARAPHASIA IN RUNNING SPEECH	Present in every utterance — Once per minute of conversation — absent		
REPETITION	0 0 1 2 4 6 8		
WORD FINDING	Fluent without information — Information proportional to fluency — Speech exclusively content words		
AUDITORY COMPREHENSION	1 15 30 45 60 75 90 59.5		
VOLUME	Hypophonic	**Normal**	Loud
VOICE	Whisper	Hoarse	**Normal**
RATE	Slow	**Normal**	Rapid

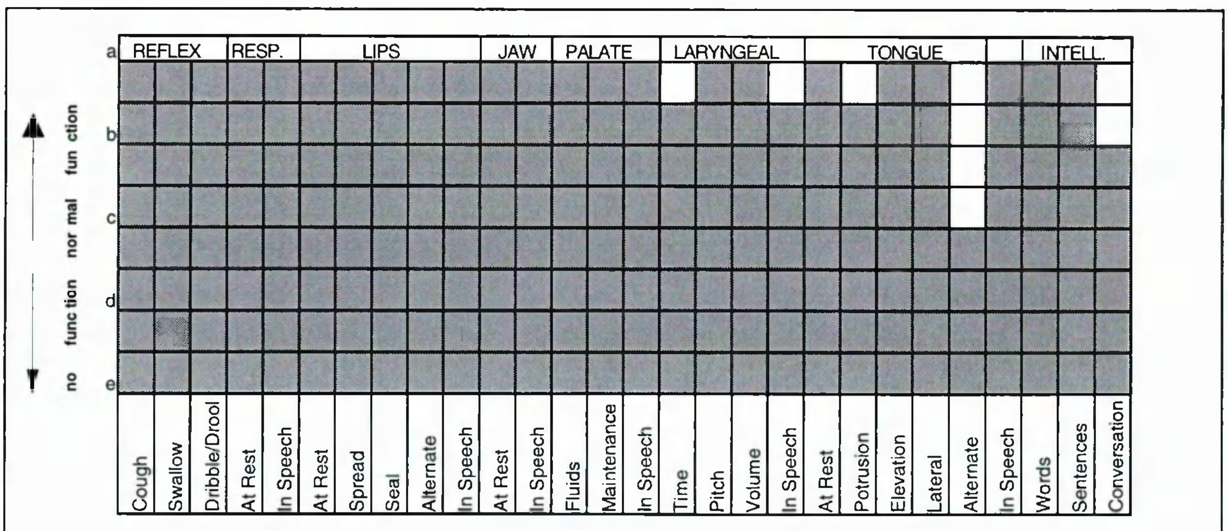
Table 37: BDAE Rating Scale Profile of Speech Characteristics for PW (Goodglass and Kaplan, 1972).

BDAE Subtest summary profile

	PERCENTILES	0		10		20		30		40		50		60		70		80		90		100
SEVERITY RATING				0		1								**2**				3		4		5
FLUENCY	ARTICULATORY RATING			1		2		4		**5**		6				7						
	PHRASE LENGTH					1		3		4		5		6		**7**						
	MELODIC LINE			1		2		4		**5**		6		7								
	VERBAL AGILITY			0		2		5		6		8		9		**11**		13		14		
AUDITORY COMPREHENSION	WORD DISCRIMINATION	0		15		25		37		46		53	**59.5**	60		64		67		70		72
	BODY-PART IDENTIFICATION	0		1		5		10		13		15		16		**17**		18				20
	COMMANDS	0		3		4		6		8		10		11	**12**	13		14		15		
	COMPLEX IDEATIONAL MATERIAL			0		2		3		**4**		5		6		8		9		11		12
NAMING	RESPONSIVE NAMING					0		1		5		10		15		20		24		27	**28**	30
	CONFRONTATION NAMING			0		9		28		43		60		72		**84**		94		105		114
	ANIMAL NAMING							0		**1**		2		3		4		6		9		23
ORAL READING	WORD READING					0		1		3		7		15		21	**24**	26		30		
	ORAL SENTENCE READING									0		1		2		4	**5**	7		9		10
REPETITION	REPETITION OF WORDS			0		2		5		7		8				9				**10**		
	HIGH-PROBABILITY					0		1				2		4		5		7		**8**		
	LOW-PROBABILITY									0		1				2		4	**5**	6		8
PARAPHASIA	NEOLOGISTIC	40		16		9		4		2		1				**0**						
	LITERAL	47		17		12		**9**		6		5		3		2		1		0		
	VERBAL	40		23		18		15		12		9		7		4		3		1		**0**
	EXTENDED	75		12		5		3		1		**0**										
AUTOMATIC SPEECH	AUTOMATIZED SEQUENCES			0		1		2		3		4		6		7				**8**		
	RECITING							0		1								**2**				
READING COMPREHENSION	SYMBOL DISCRIMINATION	0		2	**3**	5		7		8		9				10						
	WORD RECOGNITION	0		1		3		4		5		6		**7**				8				
	COMPREHENSION OF ORAL SPELLING							0		1				3		**4**		6		7		8
	WORD-PICTURE MATCHING			0		1		4		6	**7**	8		9				10				
	READING SENTENCES & PARAGRAPHS			0		1		2		3		4		5		**6**		7		8		10
WRITING	MECHANICS	1				2				3				**4**						5		
	SERIAL WRITING			0		7		18		25		30		33		40		43	**44**	46		47
	PRIMER-LEVEL DICTATION			0		1		4		6		9		11		13		**14**		15		
	SPELLING TO DICTATION									0		1		**2**		3		5		7		10
	WRITTEN CONFRONTATION NAMING							0		1		2		**3**		6		7		9		10
	SENTENCES TO DICTATION (not tested)											0		1		3		6		8		12
	NARRATIVE WRITING			0		**1**						2						3		4		
MUSIC	SINGING			0		1				**2**												
	RHYTHM			0		1								**2**								
		0		10		20		30		40		50		60		70		80		90		100

Table 38: BDAE Subtest summary profile for PW (Goodglass and Kaplan, 1972).

Frenchay Dysarthria Profile



Frenchay Dysarthria Profile (Enderby, 1983)

Figure 9: Frenchay Dysarthria Profile for PW (Enderby, 1983).

Phonetic transcriptions

Word List A

	Orthographic	Repetition 1	Repetition 2
1.	a dart	ə daɹt	ə daɹt
2.	a tip	ə tʰɪp	ə tʰɪp
3.	a leg	(t) ə lɛg	ə d lɛg
4.	a deer	ə diɾ	ə d/diɾ ə diɾ
5.	a chain	ə dⁿɛk̚ deɜ:ɹn	ə dʒ/dʒ ə dʒə ə dʒ ə tʃen
6.	a shark	ə dʒaɹk ə saɹk	ə daɹk ə/ə ʃaɹk
7.	a key	ə tʰi ə kʰi	ə kʰi
8.	the dolls	(d) dɔls ə dɔl	ðə dɔls
9.	a gear	ə giɾ	ə g̚ giɾ
10.	a book	ə b:uk	ə di ə d ə bʌk ə buk
11.	a car	ə kʰaɾ	ə kʰaɹt
12.	a beak	ə bi:k	ə bi:k
13.	a knot	ə (d) nɔt	ə nɔt
14.	the dark	ðə daɹk	ə daɹk
15.	a tick	ə tʰɪk	ə tʰɪk
16.	near	n:iɾ	n:iɾ
17.	sea	ð: s: z: si ðə di	s:i
18.	she	ðə ʃi:	ʃi: si
19.	a tear	ə diɹ	ə tʰiɾ
20.	the sun	ðə̆ sʌn	ðə sʌn
21.	a mouse	ə maus	ə daɹl no ə maus
22.	a cheer	ə tʃiɾ	ə tʃiɾ
23.	a fish	ə s: ə fɪʃ	ə fɪʃ
24.	a zoo	ə di: ə zu:	ə d/d ə zu:
25.	a sheep	ə ʃi:p	ə ʃip
26.	a brush	ə daɹt bɹʌʃ	ə bɹʌʃ
27.	a leer	ə ʔ liɾ	ə d ə liɾ
28.	a seed	ə ɹʌʃ ə sid	bɹedz ə sid
29.	a shop	ə dʒ̚ dʒɔ no ə ʃɔp	ə ʃɔp
30.	a racer	ə ɦi n ɹesə	ə ɹezɜɾ
31.	a leaf	ə lif	ənd lif

Table 39: Phonetic transcription of word list A produced by PW.

Word List B

	Orthographic	Repetition 1	Repetition 2
1.	a cocktail	ə kʰɔkə̆tɛl	ə kɔʔtel
2.	a kitkat	ə kʰɪt̚kat	ə kɪt.kat
3.	a clock	ə klɔk	ə kə̆lɔk
4.	a headlight	ə ə l ə hɛd.laɪt	ə hɛd.laɪt
5.	a tractor	ə tɹaktɜɹ	ðə tɹak.tɜɹ
6.	a weekday	ə lɪk ə lu:k ə lʌ wikde	ə wi:k.de
7.	a tickling	ə tɪkəli:	ə tɪk.lɪŋ
8.	a deckchair	ə dɛktʃɛə	ə d̚ətʲɛktʃeɹ
9.	a witchcraft	wɪtʃkɹaft	ə wɪtʃ.kɹaft
10.	a bookshop	ə bluk ə bʉk.ʃɔp	ə bʌk.ʃɔp
11.	a star	ə staɹ	ə staɹ
12.	a box	ə bɔks	ə bɔks
13.	the hats	ðə ʔhad̥s	ðə hats
14.	a squashkit	ə skwɔʃ:kɪt	ə skwɔʃ.kɪt
15.	a skirt	ə skɜɹt	ə skɜɹlt
16.	a catkin	ə kat.kɪn	ə kat̚kɪn

Table 40: Phonetic transcription of word list B produced by PW.

Phonetic transcriptions

Repetitions

"deer"	
Repetition	Phonetic Transcription
1.	ə diɾ
2.	ə diɾ
3.	ə diɾ
4.	ə diɾ
5.	ə diɾ
6.	ə diɾ
7.	ə diɾ
8.	ə djiɾ
9.	ə diɾ
10.	ə diɾ

"clock"	
Repetition	Phonetic Transcription
1.	ə klɔk
2.	ə klɔk
3.	ə klɔk
4.	ə klɔk
5.	ə klɔk
6.	ə klɔk
7.	ə k̬lɔk
8.	ə klɔk
9.	ə k̬lɔk
10.	ə klɔk

"kitkat"	
Repetition	Phonetic Transcription
1.	ə kʰɪt̚kat
2.	ə kʰɪntkat
3.	ə kɪtgat
4.	ə kɪt.kat
5.	ə kɪt.kat
6.	ə kɪt.gat
7.	ə kɪt.kat
8.	ə kɪt.kat
9.	ə kɪt.kat
10.	ə kɪt.kat

Table 41: Phonetic transcription of the repetition task produced by PW.

FC (anomic)

Boston Diagnostic Aphasia Examination

Conversational And Expository Speech

FC	there's a boy and a girl
	the boy is up the top er cupboard and this chair's is falling
	the woman is [s:]tanding front (extraneous noise)
	a woman doing the dishes
	the sink is overflowing
SLT	Why do you think she's not seen the sink overflowing?
FC	she's in line with the that (pointing to the picture)
SLT	she's in line with it, yes. D'you think she's daydreaming?
FC	yes
SLT	D'you think she knows what the children are doing?
FC	no
	she's facing the wrong way
SLT	And I think this little boy is gonna have an accident
FC	yes
	the [s: sku: sku:] stool's toppling over

SEVERITY RATING	4
AUDITORY COMPREHENSION	Scored at or above the 80th%tile for all subtests. Failed to carry out one part of the longest command. Pointed to eyebrow instead of eyelid and index finger instead of middle finger during body part identification.
ORAL EXPRESSION	Non verbal oral agility was frequently slow and occasionally demonstrated perseveration. Verbal agility movements were correct but often slow. Articulation was often rated as stiff throughout this section. Some difficulties with repeating phrases, more errors with low than high probability phrases. Some literal paraphasia noted during this section.
UNDERSTANDING WRITTEN LANGUAGE	Isolated errors during symbol and word discrimination and comprehension of oral spelling. Failed the last item in reading sentences and paragraphs.
WRITING	Not tested due to dense right sided hemiparesis and stiffness of the left side.

Table 42: Summary of BDAE for FC.

BDAE Rating Scale Profile of Speech Characteristics

SEVERITY RATING	**4**		
MELODIC LINE	1 2 3 4 5 6 7		
	absent	Limited to short phrases and stereotypes	Runs through entire sentence
PHRASE LENGTH	1 word	4 words	7 words
ARTICULATORY AGILITY	Always impaired or impossible	Normal only in familiar words and phrases	Never impaired
GRAMMATICAL FORM	None available	Limited to simple declaratives and stereotypes	Normal range
PARAPHASIA IN RUNNING SPEECH	Present in every utterance	Once per minute of conversation	absent
REPETITION	0 0 1 2 4 6 8		
WORD FINDING	Fluent without information	Information proportional to fluency	Speech exclusively content words
AUDITORY COMPREHENSION	1 15 30 45 60 75 90	86.5	
VOLUME	Hypophonic	**Normal**	Loud
VOICE	Whisper	Hoarse	**Normal**
RATE	**Slow**	Normal	Rapid

Table 43: BDAE Rating Scale Profile of Speech Characteristics for FC (Goodglass and Kaplan, 1972).

BDAE Subtest summary profile

	PERCENTILES	0	10	20	30	40	50	60	70	80		90		100
SEVERITY RATING			0	1				2		3		**4**		5
FLUENCY	ARTICULATORY RATING		1	2	4	**5**	6		7					
	PHRASE LENGTH			1	3	4	5	6	**7**					
	MELODIC LINE		1	2	4		**6**	7						
	VERBAL AGILITY		0	2	5	6	8	**9**	11	13		14		
AUDITORY COMPREHENSION	WORD DISCRIMINATION	0	15	25	37	46	53	60	64	67		70		**72**
	BODY-PART IDENTIFICATION	0	1	5	10	13	15	16	17	**18**				20
	COMMANDS	0	3	4	6	8	10	11	13	**14**		15		
	COMPLEX IDEATIONAL MATERIAL		0	2	3	4	5	6	8	9		**11**		12
NAMING	RESPONSIVE NAMING			0	1	5	10	15	20	24		27		**30**
	CONFRONTATION NAMING		0	9	28	43	60	72	84	94		105	**109**	114
	ANIMAL NAMING				0	1	2	3	4	6		9	**10**	23
ORAL READING	WORD READING			0	1	3	7	15	21	26	**29**	30		
	ORAL SENTENCE READING					0	1	2	4	7		9		**10**
REPETITION	REPETITION OF WORDS		0	2	5	7	8		9			**10**		
	HIGH-PROBABILITY			0	1		2	4	5	**7**		8		
	LOW-PROBABILITY					0	1		2	4	**5**	6		8
PARAPHASIA	NEOLOGISTIC	40	16	9	4	2	1		**0**					
	LITERAL	47	17	12	9	**6**	5	3	2	1		0		
	VERBAL	40	23	18	15	12	9	7	4	3		1		**0**
	EXTENDED	75	12	5	3	1	**0**							
AUTOMATIC SPEECH	AUTOMATIZED SEQUENCES		0	1	2	3	4	6	**7**			8		
	RECITING				0	1				**2**				
READING COMPREHENSION	SYMBOL DISCRIMINATION	0	2	5	7	8	**9**		10					
	WORD RECOGNITION	0	1	3	4	5	6	7		**8**				
	COMPREHENSION OF ORAL SPELLING				0	1		3	4	6		**7**		8
	WORD-PICTURE MATCHING		0	1	4	6	8	9		**10**				
	READING SENTENCES & PARAGRAPHS		0	1	2	3	4	5	6	7		8	**9**	10
WRITING (not tested)	MECHANICS	1		2		3		4				5		
	SERIAL WRITING		0	7	18	25	30	33	40	43		46		47
	PRIMER-LEVEL DICTATION		0	1	4	6	9	11	13	14		15		
	SPELLING TO DICTATION					0	1	2	3	5		7		10
	WRITTEN CONFRONTATION NAMING				0	1	2	3	6	7		9		10
	SENTENCES TO DICTATION						0	1	3	6		8		12
	NARRATIVE WRITING		0	1			2			3		4		
MUSIC	SINGING		0	**1**		2								
	RHYTHM		0	1				**2**						
		0	10	20	30	40	50	60	70	80		90		100

Table 44: BDAE Subtest summary profile for FC (Goodglass and Kaplan, 1972).

Frenchay Dysarthria Profile

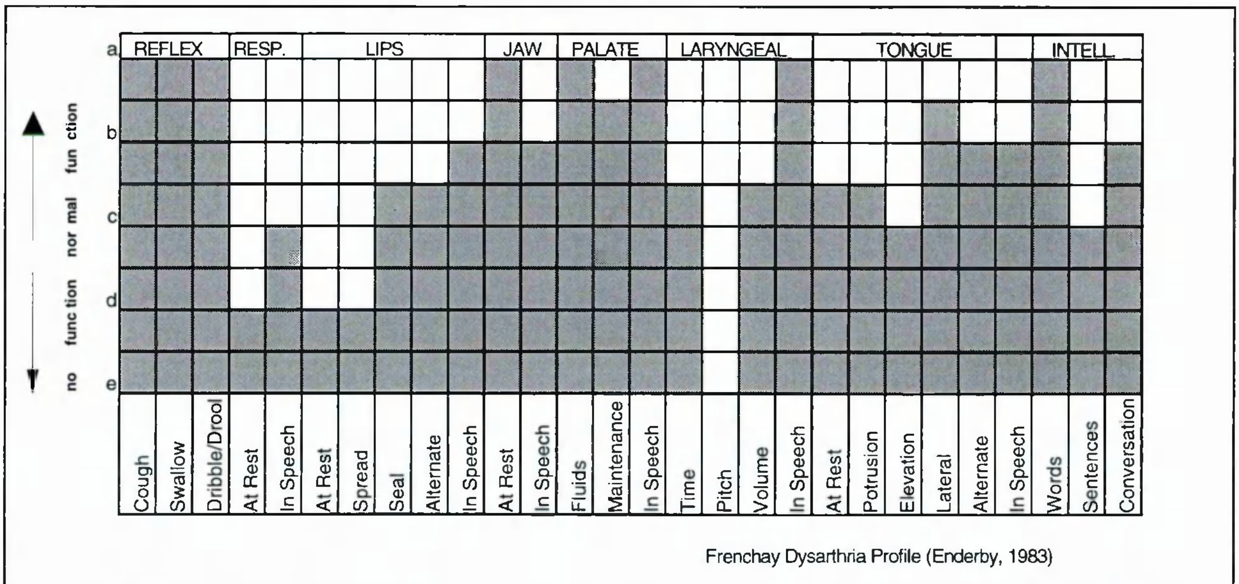


Figure 10: Frenchay Dysarthria Profile for FC (Enderby, 1983).

Phonetic transcriptions

Word List A

	Orthographic	Repetition 1	Repetition 2
1.	a dart	ʌ dat	ə daɹt
2.	a tip	ʌ ʈɪp	ʌ tʰɪp
3.	a leg	ʌ lɛg	ʌ lɛg
4.	a deer	ʌ diɹ	ʌ diɹ
5.	a chain	ʌ tʃedʒ tʃen	ʌ tʃɛnd
6.	a shark	ʌ ʃak	tə ʌ sə ʃaɹk ʌ ʃaɹk
7.	a key	ʌ g̊i	ʌ k̬i
8.	the dolls	ðə dɔlz	ðə dɔlz
9.	a gear	ʌ giɹ	ə d̥ ʌ giɹ ʌ giɹ
10.	a book	ʌ buk	ʌ g˺ buk
11.	a car	ʌ kʰaɹ	ʌ kʰaɹ
12.	a beak	ʌ bik	ʌ bik
13.	a knot	ʌ nɔt	ʌ d nɔt
14.	the dark	ðə daɹk	ðə daɹk
15.	a tick	ʌ tʰɪk	ʌ tʰɪk
16.	near	niɹ	niɹ
17.	sea	ðet si	ðə s:i:
18.	she	ʃi	tʃi:
19.	a tear	ʌ tʰiɹ	ʌθ tʰiɹ
20.	the sun	ðə sʌn	ðə sʌn
21.	a mouse	ʌ maus	ðə maus
22.	a cheer	ʌ tʃ:i	ʌ tʃiɹ
23.	a fish	ʌ θis fɪʃ	θ ʌ fɪʃ
24.	a zoo	ʌ zu:	θis ʌ zu:
25.	a sheep	ʌ ʃip	ʌ ʃɪp
26.	a brush	ʌ bɹʌʃ	ʌ bɹuʃ
27.	a leer	ʌ liɹ	ʌ liɹ
28.	a seed	ʌ si:z sɪd ʌ sɪd	ʌ sɪd
29.	a shop	ʌ ʃɔp	ʌ ʃɔp
30.	a racer	ʌ ɹezɜɹ	ʌ ɹezɜɹ
31.	a leaf	ʌ luk luf lɪf	ʌ lif:

Table 45: Phonetic transcription of word list A produced by FC.

Word List B

	Orthographic	Repetition 1	Repetition 2
1.	a cocktail	ʌ kʰɔk˺tel	ʌ kʰɔk˺tel
2.	a kitkat	ʌ k̬ɪt˺gat	ʌ k̬ɪt˺gat
3.	a clock	ʌ k̬əlɔk	ʌ kʰə̆lɔk
4.	a headlight	ʌ hed˺laɪt	ʌ hedɹaɪ laɪt˺
5.	a tractor	ʌ tɹaxtə	ʌ tɹaktə
6.	a weekday	ʌ wik˺de	ʌ wik˺de
7.	a tickling	ʌ tʰɪk˺lɪŋ	ʌ tʰɪklɪŋ
8.	a deckchair	ʌ dɛk dɛk.tʃɜɹ	ʌ dɛ dʒɛk tʃ dɛktʃɛɹ ʌ dɛktʃɛɹ
9.	a witchcraft	ðə ʌ wɪʃkɹaf	ðə wɪʃx wɪtʃkɹaf
10.	a bookshop	ʌ buksʃɔp	ðə baɹ buktʃɔp ʌ bukʃɔp
11.	a star	ʌ staɹ	ʌ staɹ
12.	a box	ʌ bɔks	ʌ bɔks
13.	the hats	ðə hʌts	ðə hats
14.	a squashkit	ʌ skwɔʃgɪt˺	ʌ s:gwɔʃgɪt
15.	a skirt	ʌ skɜɹt	ʌ skɜɹt
16.	a catkin	ʌ k̬atgɪn	ʌ k̬atgɪn

Table 46: Phonetic transcription of word list B produced by FC.

Phonetic transcriptions

Repetitions

"deer"	
Repetition	Phonetic Transcription
1.	ə diɾ
2.	ə diə
3.	ə diə
4.	ə diə
5.	ə diə
6.	ə diə
7.	ə diə
8.	ə diə
9.	ə diɾ
10.	ə diə

"clock"	
Repetition	Phonetic Transcription
1.	ə d̚klɔk
2.	ə klɔk
3.	ə klɔk
4.	ə klɔk
5.	ə klɔk
6.	ə klɔk
7.	ə klɔk
8.	ə klɔkʰ
9.	ə klɔkʰ
10.	ə klɔkʰ

"kitkat"	
Repetition	Phonetic Transcription
1.	ə k̬ɪtk̬at
2.	ə k̬ɪtk̬at
3.	ə kʰɪtgat
4.	ə kʰɪtkat
5.	ə k̬ɪtgat
6.	ə k̬ɪtk̬at
7.	ə k̬ɪtgat
8.	ə k̬ɪtgat
9.	ə k̬ɪtk̬at
10.	ə kʰɪtkat

Table 47: Phonetic transcription of the repetition task produced by FC.

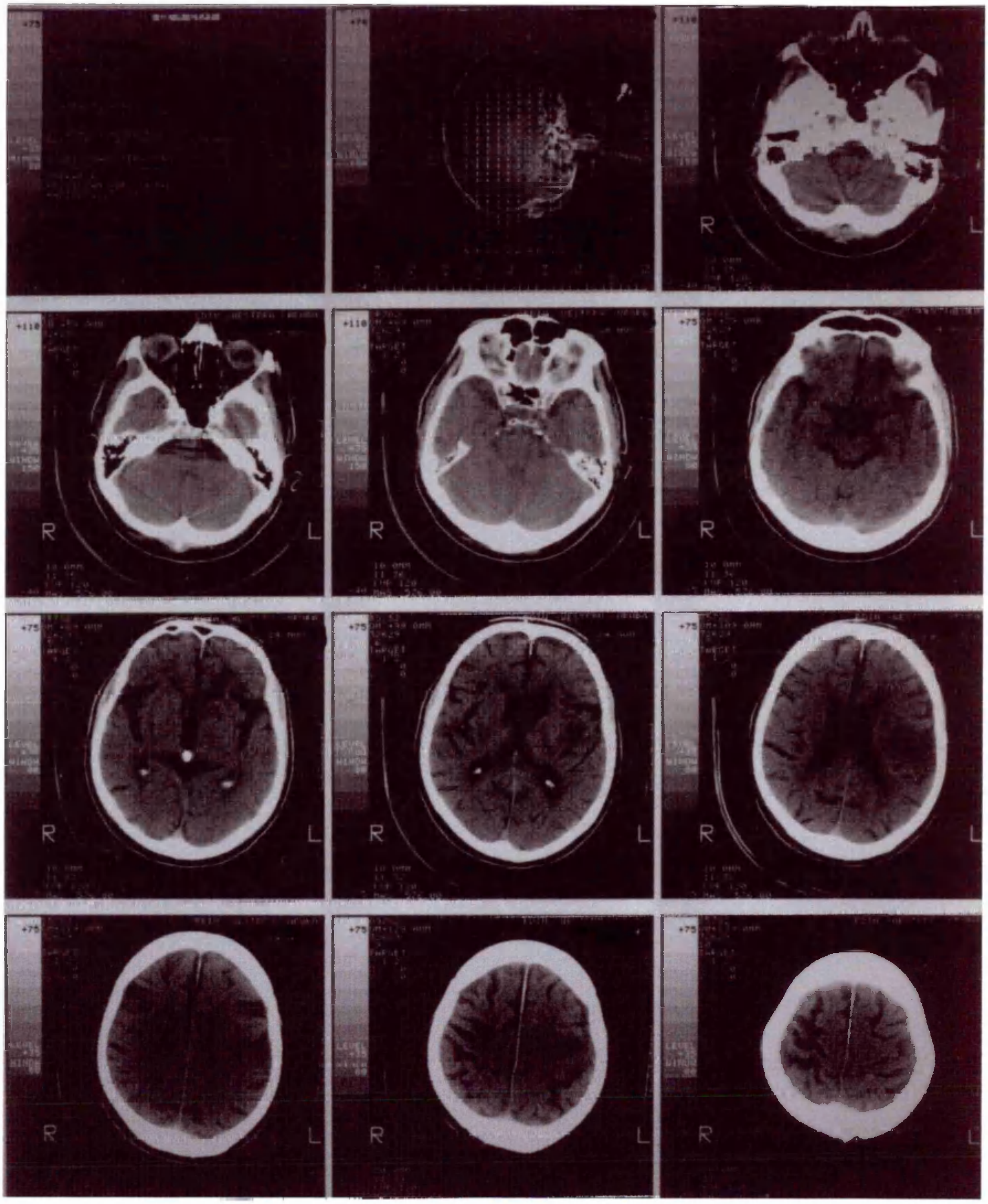


Figure 11: CT scan for FC.

HJ (anomic)

Boston Diagnostic Aphasia Examination

Conversational And Expository Speech

HJ There's somebody washing dishes.

The wash basin is overflowing onto the floor.

There's a boy on a stool which is ready to topple over. He's getting a cookie jar.

There's a girl. She's getting a cookie from the boy.

The stool's on one leg.

SLT Which room do you think this is?

HJ The kitchen.

SEVERITY RATING	5
AUDITORY COMPREHENSION	Scored above the 80th %tile for all subtests. Needed to be cued for identification of "cone" and took over 5 seconds to identify 1936. Two errors were made during complex ideational material.
ORAL EXPRESSION	All non verbal and verbal movements were performed correctly although a reduced rate was evident for most actions. A single error during repeating phrases (omitted the word "plump" during a low probability phrase) but no errors throughout the remainder of this section. Some difficulty with animal naming (scoring at the 70th %tile) indicating a mild word finding difficulty.
UNDERSTANDING WRITTEN LANGUAGE	No problems during symbol and word discrimination, phonetic association and word-picture matching. Difficulties choosing the correct word or phrase to complete the sentence when reading longer sentences and paragraphs.
WRITING	Scored well during this section. Limited narrative writing for Cookie Theft.

Table 48: Summary for BDAE for HJ.

BDAE Rating Scale Profile of Speech Characteristics

SEVERITY RATING	**5**		
MELODIC LINE	1 2 3 4 5 6 7 absent	Limited to short phrases and stereotypes	Runs through entire sentence
PHRASE LENGTH	1 word	4 words	7 words
ARTICULATORY AGILITY	Always impaired or impossible	Normal only in familiar words and phrases	Never impaired
GRAMMATICAL FORM	None available	Limited to simple declaratives and stereotypes	Normal range
PARAPHASIA IN RUNNING SPEECH	Present in every utterance	Once per minute of conversation	absent
REPETITION	0 0 1 2 4 6 8		
WORD FINDING	Fluent without information	Information proportional to fluency	Speech exclusively content words
AUDITORY COMPREHENSION	1 15 30 45 60 75 90		
VOLUME	Hypophonic	**Normal**	Loud
VOICE	Whisper	Hoarse	**Normal**
RATE	Slow	**Normal**	Rapid

Table 49: BDAE Rating Scale Profile of Speech Characteristics for HJ (Goodglass and Kaplan, 1972).

BDAE Subtest summary profile

	PERCENTILES	0	10	20	30	40	50	60	70	80	90	100
SEVERITY RATING			0	1				2		3	4	**5**
FLUENCY	ARTICULATORY RATING		1	2	**4**	5	6		7			
	PHRASE LENGTH			1	3	4	5	6	**7**			
	MELODIC LINE		1	2	4		6	**7**				
	VERBAL AGILITY		0	2	5	6 **7**	8	9	11	13	14	
AUDITORY COMPREHENSION	WORD DISCRIMINATION	0	15	25	37	46	53	60	64	67 **69**	70	72
	BODY-PART IDENTIFICATION	0	1	5	10	13	15	16	17	18		**20**
	COMMANDS	0	3	4	6	8	10	11	13	14	**15**	
	COMPLEX IDEATIONAL MATERIAL		0	2	3	4	5	6	8	9 **10**	11	12
NAMING	RESPONSIVE NAMING			0	1	5	10	15	20	24	27	**30**
	CONFRONTATION NAMING		0	9	28	43	60	72	84	94	105	**114**
	ANIMAL NAMING				0	1	2	3	**4**	6	9	23
ORAL READING	WORD READING			0	1	3	7	15	21	26	**30**	
	ORAL SENTENCE READING					0	1	2	4	7	9	**10**
REPETITION	REPETITION OF WORDS		0	2	5	7	8		9		**10**	
	HIGH-PROBABILITY			0	1		2	4	5	7	**8**	
	LOW-PROBABILITY					0	1		2	4	6 **7**	8
PARAPHASIA	NEOLOGISTIC	40	16	9	4	2	1		**0**			
	LITERAL	47	17	12	9	6	5	3	2	1	**0**	
	VERBAL	40	23	18	15	12	9	7	4	3	1	**0**
	EXTENDED	75	12	5	3	1	**0**					
AUTOMATIC SPEECH	AUTOMATIZED SEQUENCES		0	1	2	3	4	6	7		**8**	
	RECITING				0	1				**2**		
READING COMPREHENSION	SYMBOL DISCRIMINATION	0	2	5	7	8	9		**10**			
	WORD RECOGNITION	0	1	3	4	5	6	7		**8**		
	COMPREHENSION OF ORAL SPELLING				0	1		3	4	6	7	**8**
	WORD-PICTURE MATCHING		0	1	4	6	8	9		**10**		
	READING SENTENCES & PARAGRAPHS		0	1	2	3	4	5	**6**	7	8	10
WRITING	MECHANICS	1		2		3		4			**5**	
	SERIAL WRITING		0	7	18	25	30	33	40	43	46	**47**
	PRIMER-LEVEL DICTATION		0	1	4	6	9	11	13	14	**15**	
	SPELLING TO DICTATION					0	1	2	3	5	7 **8**	10
	WRITTEN CONFRONTATION NAMING				0	1	2	3	6	7	9	**10**
	SENTENCES TO DICTATION (not tested)						0	1	3	6	8	12
	NARRATIVE WRITING		0	1			**2**			3	4	
MUSIC	SINGING		0	1		**2**						
	RHYTHM		0	**1**				2				
		0	10	20	30	40	50	60	70	80	90	100

Table 50: BDAE Subtest summary profile for HJ (Goodglass and Kaplan, 1972).

Frenchay Dysarthria Profile

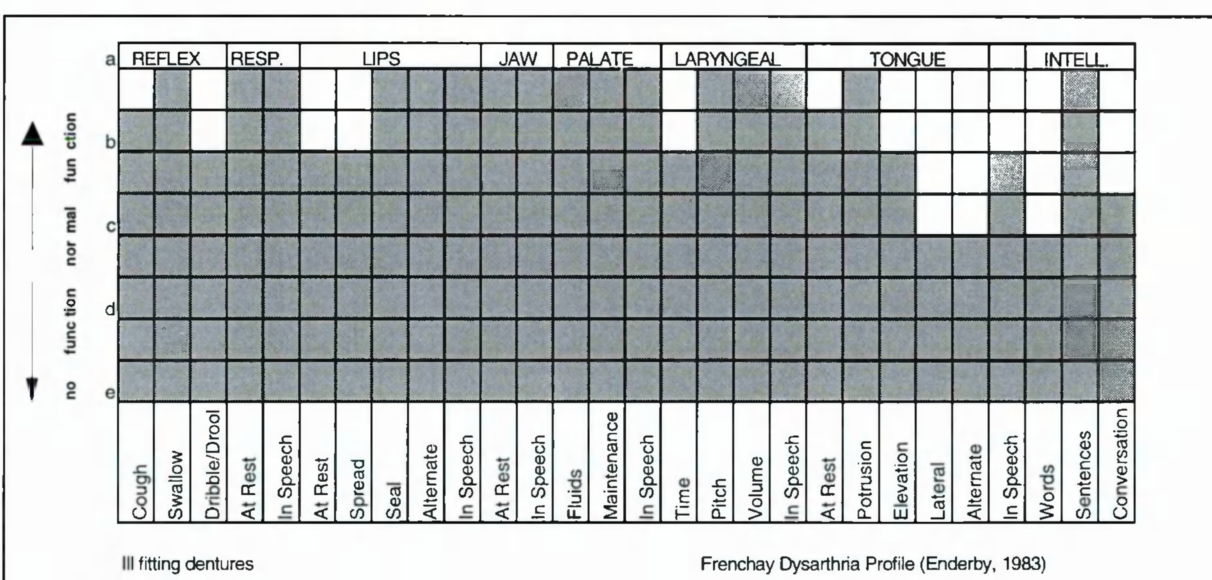


Figure 12: Frenchay Dysarthria Profile for HJ (Enderby, 1983).

Phonetic transcriptions

Word List A

	Orthographic	Repetition 1	Repetition 2
1.	a dart	ə daɹt	ə daɹt
2.	a tip	ə t^{h}ɪp	ə t^{h}ɪp
3.	a leg	ə lɛg	ə lɛg
4.	a deer	ə diɹ	ə diɹ
5.	a chain	ə t^{h}/t^{h}/tʃen	ə tʃen
6.	a shark	ə ʃaɹk	ə s:aɹk
7.	a key	ə k^{h}i	ə k̬i
8.	the dolls	ðə dɔl̥s	ðə dɔlz
9.	a gear	ə qiɹ	ə giɹ
10.	a book	ə bʌk	ə buk
11.	a car	ə k^{h}aɹ	ə k^{h}aɹ
12.	a beak	ə bik	ə bik
13.	a knot	ə nɔt	ə nɔt
14.	the dark	ðə d̥aɹk	ðə daɹk
15.	a tick	ə t^{h}ɪk	ə t^{h}ɪk
16.	near	niɹ	niɹ
17.	sea	ðə sti	ðə sti
18.	she	ʃ:i	sti
19.	a tear	ə t^{h}iɹ	ə t^{h}iɹ
20.	the sun	ðə ts:ʌn	ðə t͡sʌn
21.	a mouse	ə mɑus	ə maus
22.	a cheer	ə dʒiɹ	ə ɟdiə
23.	a fish	ə fɪs	ə f:ɪs
24.	a zoo	ə z̥u	ə dzu
25.	a sheep	ə sip	ə tsip
26.	a brush	ə bʌʃ	ə b^{w}ɹʌs
27.	a leer	ə liɹ	ə d̥ liɹ
28.	a seed	ə stid	ə s:id
29.	a shop	ə tʃɔp	ə sʃɔp
30.	a racer	ə ɹesə	əs ɹesə
31.	a leaf	ə lif	ə lif:

Table 51: Phonetic transcription for word list A produced by HJ.

Word List B

	Orthographic	Repetition 1	Repetition 2
1.	a cocktail	ə k̬ɔkseɪlz	ə k̬ɔktɛl
2.	a kitkat	ə ɢɪt.kat	ə ɣɪtk^{h}at
3.	a clock	ə k^{h}əlɔk	ə k^{h}əlɔk
4.	a headlight	ə htɛdɹaɪt	ə hɛdɹaɪt
5.	a tractor	ə t^{w}ɹaktə ə ɯ:aktə	ə t^{w}ɹaktɔ
6.	a weekday	ə wi:qde	ə wi:kdeɪ
7.	a tickling	ə t^{h}ɪkəg˞lɪŋ	ə ɯɪkəlɪŋ
8.	a deckchair	ə dʲɛktʃɛə	ə dɛktʃɜɹ
9.	a witchcraft	ðə wɪtʃ.kɹafs	ðə wɪtʃxa:ft
10.	a bookshop	ə bukdɹɔp	ə bukʃɔp
11.	a star	ə sa:	ə s:daɹ
12.	a box	ə bɔks	ə bɔk˺s
13.	the hats	ðə hak͡ts	ðə hats
14.	a squashkit	ə s:gwɔsgɪt	ə s:kwɔʃgɜɹk
15.	a skirt	ə s:kɜɹt	ə s:kɜɹt
16.	a catkin	ə qatɢɪn	ə k̬at.kɪn

Table 52: Phonetic transcription for word list B produced by HJ.

Phonetic transcriptions

Repetitions

"deer"	
Repetition	Phonetic Transcription
1.	ə diɹ
2.	ə diɹ
3.	ə diɹ
4.	ə diɹ
5.	ə diɹ
6.	ə diɹ
7.	ə diɹ
8.	ə diɹ
9.	ə diɹ
10.	ə diɹ

"clock"	
Repetition	Phonetic Transcription
1.	ə kʰəlɔk
2.	ə kʰəlɔk
3.	ə kʰəlɔk
4.	ə kʰəlɔk
5.	ə kʰəlɔk
6.	ə klɔk
7.	ə kʰəlɔk
8.	ə kʰəlɔk
9.	ə kʰəlɔk
10.	ə klɔk

"kitkat"	
Repetition	Phonetic Transcription
1.	ə kʰɪt..kʰat
2.	ə kʰɪt..kʰat
3.	ə kʰɪt..kʰat
4.	ə gɪt.kat
5.	ə kʰɪt.kat
6.	ə kʰɪt.kat
7.	ə kʰɪt.kat
8.	ə kʰɪt.kat
9.	ə kʰɪt.kat
10.	ə kʰɪt.kat

Table 53: Phonetic transcription of the repetition task produced by HJ.

HL (anomic)

Boston Diagnostic Aphasia Examination

Conversational And Expository Speech

HL the sink is overflowing

the eh the girl is standing [ə] sink drying plate

boy is gonna get cookies for the little gel

he's standing on a stool which is naughty

the stool is capsizing

the they fall down

um

I say [s/s/f] sink is overflowing, no?

SLT Yes. What about the mother? Is there anything strange about it?

HL she's turning her back on the youngsters

she's getting your feet wet

SEVERITY RATING	4
AUDITORY COMPREHENSION	Very few errors throughout this section, scoring at or above the 80th %tile for all subtests.
ORAL EXPRESSION	Oral agility noted to be slow for both verbal and non verbal movements. Difficulty reciting the alphabet, but all other automatized sequences were complete. During repetition of words, articulation often reported to be "stiff". Frequent literal paraphasic errors. During reading, occasionally omits a word, changes a tense or misses a plural marking.
UNDERSTANDING WRITTEN LANGUAGE	Problems only with reading sentences and paragraphs where HL unable to access meaning.
WRITING	Upper and lower case writing easily legible. Some problems with spelling to dictation and more complex words. Produced 4 written statements about the Cookie Theft showing connected sequences. Two out of three sentences were written successfully to dictation.

Table 54: Summary of BDAE for HL.

BDAE Rating Scale Profile of Speech Characteristics

SEVERITY RATING	4		
MELODIC LINE	1 2 3 4 5 6 7 absent	Limited to short phrases and stereotypes	Runs through entire sentence
PHRASE LENGTH	1 word	4 words	7 words
ARTICULATORY AGILITY	Always impaired or impossible	Normal only in familiar words and phrases	Never impaired
GRAMMATICAL FORM	None available	Limited to simple declaratives and stereotypes	Normal range
PARAPHASIA IN RUNNING SPEECH	Present in every utterance	Once per minute of conversation	absent
REPETITION	0 0 1 2 4 6 8		
WORD FINDING	Fluent without information	Information proportional to fluency	Speech exclusively content words
AUDITORY COMPREHENSION	1 15 30 45 60 75 90 (86)		
VOLUME	Hypophonic	**Normal**	Loud
VOICE	Whisper	Hoarse	**Normal**
RATE	Slow	**Normal**	Rapid

Table 55: BDAE Rating Scale Profile of Speech Characteristics for HL (Goodglass and Kaplan, 1972).

BDAE Subtest summary profile

	PERCENTILES	0		10		20		30		40		50		60		70		80		90		100
SEVERITY RATING				0		1								2				3		**4**		5
FLUENCY	ARTICULATORY RATING			1		2		4		5		6				7						
	PHRASE LENGTH					1		3		4		5		6		**7**						
	MELODIC LINE			1		2		4				6		**7**								
	VERBAL AGILITY			0		2		5		6		**8**		9		11		13		14		
AUDITORY COMPREHENSION	WORD DISCRIMINATION	0		15		25		37		46		53		60		64		67		**70**		72
	BODY-PART IDENTIFICATION	0		1		5		10		13		15		16		17		**18**				20
	COMMANDS	0		3		4		6		8		10		11		13		14		**15**		
	COMPLEX IDEATIONAL MATERIAL			0		2		3		4		5		6		8		9	**10**	11		12
NAMING	RESPONSIVE NAMING					0		1		5		10		15		20		24		27		**30**
	CONFRONTATION NAMING			0		9		28		43		60		72		84		94		105	**112**	114
	ANIMAL NAMING							0		1		2		3		4		6		9	**15**	23
ORAL READING	WORD READING					0		1		3		7		15		21		26		30		
	ORAL SENTENCE READING									0		1		2		4	**5**	7		9		10
REPETITION	REPETITION OF WORDS			0		2		5		7		8				**9**				10		
	HIGH-PROBABILITY					0		1				2		4		**5**		7		8		
	LOW-PROBABILITY									0		1				2		4		**6**		8
PARAPHASIA	NEOLOGISTIC	40		16		9		4		2		1				**0**						
	LITERAL	47		17		12		9		6		**5**		3		2		1		0		
	VERBAL	40		23		18		15		12		9		7		4		3	**2**	1		0
	EXTENDED	75		12		5		3		1		**0**										
AUTOMATIC SPEECH	AUTOMATIZED SEQUENCES			0		1		2		3		4		6		**7**				8		
	RECITING							0		1								**2**				
READING COMPREHENSION	SYMBOL DISCRIMINATION	0		2		5		7		8		9				**10**						
	WORD RECOGNITION	0		1		3		4		5		6		7				**8**				
	COMPREHENSION OF ORAL SPELLING							0		1				3		**4**		6		7		8
	WORD-PICTURE MATCHING			0		1		4		6		8		**9**				10				
	READING SENTENCES & PARAGRAPHS			0		1		2		3		4		**5**		6		7		8		10
WRITING	MECHANICS	1				2				3				**4**						5		
	SERIAL WRITING			0		7		18		25		30		33		40		43		46		47
	PRIMER-LEVEL DICTATION			0		1		4		6		9		11		13		**14**		15		
	SPELLING TO DICTATION									0		1		2		3	**6**	5		7		10
	WRITTEN CONFRONTATION NAMING							0		1		2		3		6		7		9		**10**
	SENTENCES TO DICTATION											0		1		3		6		8	**10**	12
	NARRATIVE WRITING			0		1						2						**3**		4		
MUSIC	SINGING			0		1				**2**												
	RHYTHM			0		1								**2**								
		0		10		20		30		40		50		60		70		80		90		100

Table 56: BDAE Subtest summary profile for HL (Goodglass and Kaplan, 1972).

Frenchay Dysarthria Profile

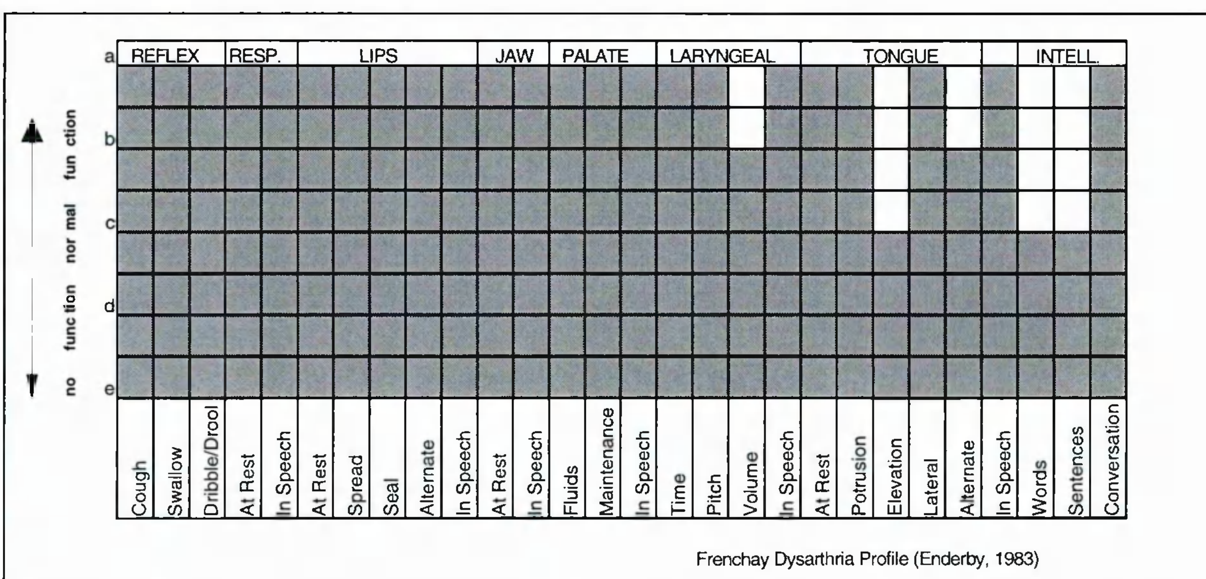


Figure 13: Frenchay Dysarthria Profile for HL (Enderby, 1983).

Phonetic transcriptions

Word List A

	Orthographic	Repetition 1	Repetition 2
1.	a dart	ə daɹt	ə daɹt
2.	a tip	ə tʰɪp	ə tʰɪp
3.	a leg	ə lɛg	ə lɛg
4.	a deer	ə diɹ	ə diɹ
5.	a chain	ə tʃen	ə tʃen
6.	a shark	ə tʃ: ʃaɹk	ə ʃaɹk
7.	a key	ə kʰi	ə kʰi
8.	the dolls	ðə dɔlz	ðə dɔlz
9.	a gear	ə giɹ	ə giɹ
10.	a book	ə buk	ə buk
11.	a car	ə kʰaɹ	ə kʰaɹ
12.	a beak	ə bəlik ə bik	ə/ə bik
13.	a knot	ə nɔt	ə nɔt
14.	the dark	ðə daɹk	ðə daɹk
15.	a tick	ə tʰɪk	ə tʰɪk
16.	near	niɹ	niɹ
17.	sea	ðə si	ðə si
18.	she	ʃi	ʃi
19.	a tear	ə tʰiɹ	ə tʰiɹ
20.	the sun	ðə sʌn	ðə sʌn
21.	a mouse	ə fɪʃ:	ə maus
22.	a cheer	ə tʃiɹ	ə tʃiɹ
23.	a fish	ə fɪʃ:	ə fɪʃ
24.	a zoo	ə z̥	ə s̬u
25.	a sheep	ə ʃip	ə ʃip
26.	a brush	ə bɹʌʃ	ə bɹʌʃ:
27.	a leer	ə liɹ	ə liɜɹ
28.	a seed	ə sid	ə s:id
29.	a shop	ə ʃɔp	ə ʃɔp
30.	a racer	ə ɹezə	ə ɹezə
31.	a leaf	ə/ə lif	ə lif:

Table 57: Phonetic transcription of word list A produced by HL.

Word List B

	Orthographic	Repetition 1	Repetition 2
1.	a cocktail	ə kʰɔt˺tel	ə kʰɔt˺tel
2.	a kitkat	ə kʰɪtikat ə kʰɪtikat	ə kʰɪtkat
3.	a clock	ə kʰəlɔk	ə kʰəlɔk
4.	a headlight	ə hedəlaɪt	ə hedlaɪt
5.	a tractor	ə tɹaktə	ə tɹaktə
6.	a weekday	ə wik.de	ə wik.de
7.	a tickling	ə tʰɪkəlɪn	ə tʰɪkəlɪn
8.	a deckchair	ə dɛktʃeɹ	ə d:ektʃeɹ
9.	a witchcraft	ðə wɪʃkɹaft	ðə wɪʃ:kɹaft
10.	a bookshop	ə b:ukʃɔp	ə bukʃɔp ə bukʃɔp
11.	a star	ə s:taɹ	ə staɹ
12.	a box	ə bɔks	ə bɔks
13.	the hats	ðə h:ats	ða hats
14.	a squashkit	ə ks:kwɔʃkɪt	ə ˈts:kwɔʃkɪt
15.	a skirt	ə skɜɹt	ə ˈtskɜɹt
16.	a catkin	ək/kʰat˺tɪn əkʰatɪn ə kʰat˺kɪn	ə katkɪns

Table 58: Phonetic transcription of word list B produced by HL.

Phonetic transcriptions

Repetitions

“deer”	
Repetition	Phonetic Transcription
1.	ə diɹ
2.	ə diɹ
3.	ə diɹ
4.	ə diɹ
5.	ə diɹ
6.	ə diɹ
7.	ə diɹ
8.	ə diɹ
9.	ə diɹ
10.	ə diɹ

“clock”	
Repetition	Phonetic Transcription
1.	ə klɔk
2.	ə klɔk
3.	ə klɔk
4.	ə klɔk
5.	ə klɔk
6.	ə klɔk
7.	ə klɔk
8.	ə klɔk
9.	ə klɔk
10.	ə klɔk

“kitkat”	
Repetition	Phonetic Transcription
1.	ə k^hɪtkat
2.	ə k^hɪtkat
3.	ə k^hɪt̚kat
4.	ə k^hɪt̚kat
5.	ə k^hɪtkat
6.	ə k^hɪtkat
7.	ə k^hɪtkat
8.	ə k^hɪtkat
9.	ə k^hɪtkat
10.	ə k^hɪtkat

Table 59: Phonetic transcription of the repetition task produced by HL.

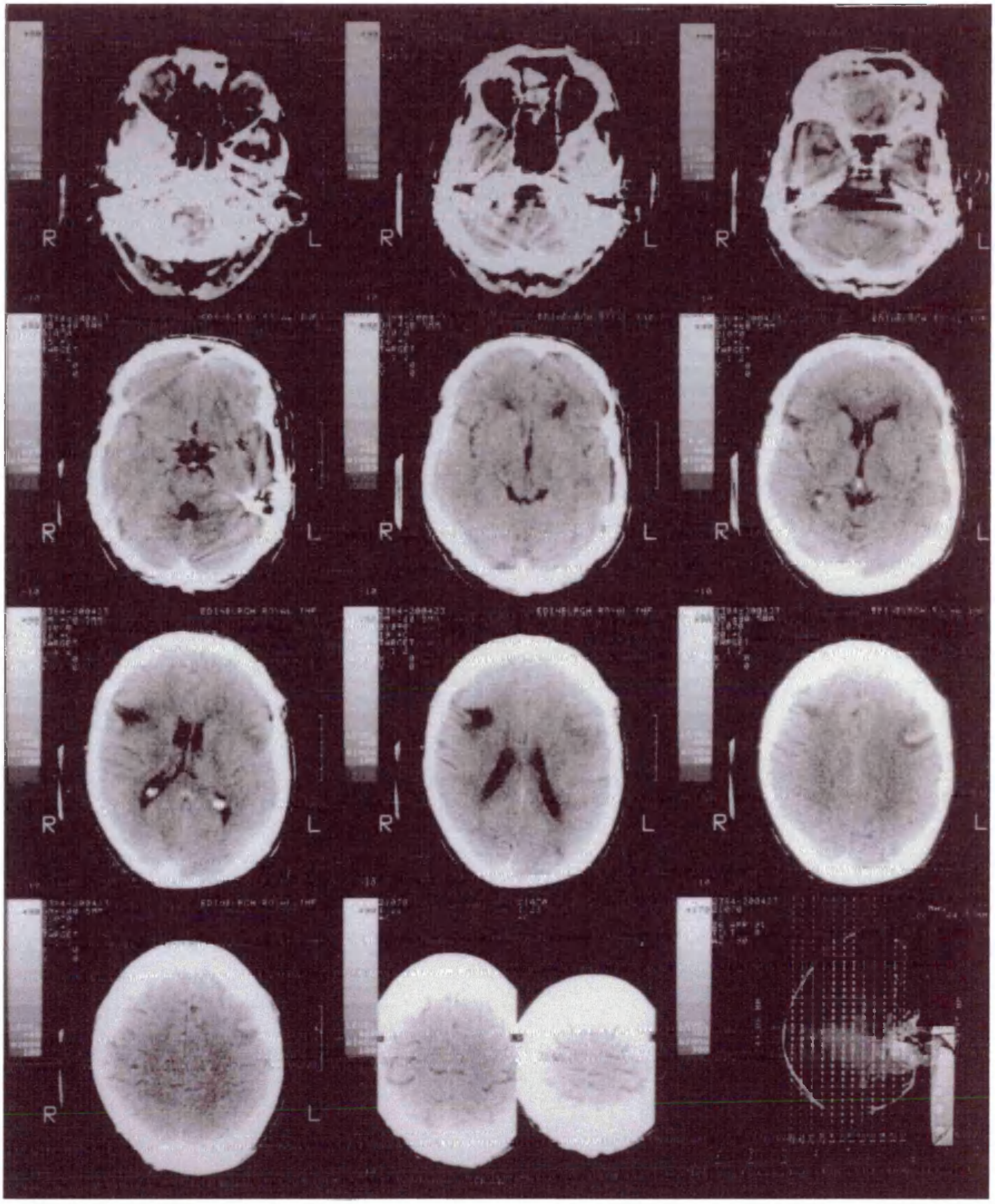


Figure 14: CT scan for HL.

Appendix B

Chi Square Analysis

H_0 = There is no real difference between the observed values and the expected values.

H_1 = There is a difference between the observed and the expected values.

Critical Values: $\alpha = 0.05$ 1 df 3.841

kitkat 6	1	2	3	4	5
Observed	14	18	14	22	2
Expected	14	14	14	14	14
O-E	0	4	0	8	- 12
$(O-E)^2$	0	16	0	64	144
$(O-E)^2/E$	0	1.143	0	4.571	10.286

$\sum (O-E)^2/E = 16$ **Rejects the H_0 at p >0.005**

kitkat 7	1	2	3	4	5
Observed	24	28	12	5	1
Expected	14	14	14	14	14
O-E	10	14	- 2	- 9	- 13
$(O-E)^2$	100	196	4	81	169
$(O-E)^2/E$	7.143	14	0.286	5.786	12.071

$\sum (O-E)^2/E = 39.286$ **Rejects the H_0** at p >0.005

deer 2	1	2	3	4	5
Observed	38	30	2	0	0
Expected	14	14	14	14	14
O-E	24	16	- 12	- 14	- 14
$(O-E)^2$	576	256	144	196	196
$(O-E)^2/E$	41.143	18.286	10.286	14	14

$\sum (O-E)^2/E = 69.714$ **Rejects the H_0** at p >0.005

kitkat 8	1	2	3	4	5
Observed	5	4	5	23	33
Expected	14	14	14	14	14
O-E	- 9	- 10	- 9	- 9	19
$(O-E)^2$	81	100	81	81	361
$(O-E)^2/E$	5.786	7.143	5.786	5.786	25.786

$\sum (O-E)^2/E = 50.286$ **Rejects the H_0** at p >0.005

key 2	1	2	3	4	5
Observed	67	3	0	0	0
Expected	14	14	14	14	14
O-E	53	- 11	- 14	- 14	- 14
$(O-E)^2$	2809	121	196	196	196
$(O-E)^2/E$	200.643	8.643	14	14	14

$\sum (O-E)^2/E = 251.286$ **Rejects the H_0** at p >0.005

car 2	1	2	3	4	5
Observed	0	0	0	4	66
Expected	14	14	14	14	14
O-E	-14	-14	-14	- 10	52
$(O-E)^2$	196	196	196	100	2704
$(O-E)^2/E$	14	14	14	7.143	193.143

$\sum (O-E)^2/E = 242.286$ **Rejects the H_0** at p >0.005

tickling	1	2	3	4	5
Observed	2	3	10	30	25
Expected	14	14	14	14	14
O-E	- 12	- 11	- 4	16	11
$(O-E)^2$	144	121	16	256	121
$(O-E)^2/E$	10.286	8.643	1.143	18.286	8.643

$\sum (O-E)^2/E = 47$ **Rejects the H_0** at $p > 0.005$

tick 2	1	2	3	4	5
Observed	44	14	10	2	0
Expected	14	14	- 4	14	14
O-E	30	0	16	- 12	- 14
$(O-E)^2$	900	0	256	144	196
$(O-E)^2/E$	64.286	-	18.286	10.286	14

$\sum (O-E)^2/E = 106.857$ **Rejects the H_0** at $p > 0.005$

Appendix C

Substitutions

FM (Broca's aphasic with AOS)

Target	Phonetic transcription	Lingual/palatal contact patterns
shark 1	a: ʃa:ɹp	WF alveolar contacts
shark 2	a: tʃaɹp	WF full alveolar closure typical of a stop gesture
gear 2	a: diɹ	EPG patterns confirm perceptual analysis

Table 1: EPG contact patterns for perceived substitutions produced by FM.

MU (Broca's aphasic with AOS)

Target	Phonetic transcription	Lingual/palatal contact patterns
key 1	ʌ tʰi	EPG patterns confirm perceptual analysis
gear 1	ə diɹ	EPG patterns confirm perceptual analysis
book 1	ə put	EPG patterns confirm perceptual analysis
car 1	ə tʰaɹ	EPG patterns confirm perceptual analysis
beak 1	ə ɸ/pi:pt	EPG patterns confirm perceptual analysis
dark 1	ðə t̬ aɹt	EPG patterns confirm perceptual analysis
tick 1	ðə tʰɪt	EPG patterns confirm perceptual analysis
cocktail 2	ʌ tʰɔktɛl	Full velar closure typical of a stop gesture
tickling 2	ðə kɹɪktɹɪn	velar MAG in addition to correct alveolar contact pattern

Table 2: EPG contact patterns for perceived substitutions produced by MU.

BA (Broca's aphasic without AOS)

Target	Phonetic transcription	Lingual/palatal contact patterns
cocktail 1	tʰɔt̚tel	EPG patterns confirm perceptual analysis

Table 3: EPG contact patterns for perceived substitutions produced by BA.

IE (conduction aphasic)

Target	Phonetic transcription	Lingual/palatal contact patterns
key 1	ə tʰi:	EPG patterns confirm perceptual analysis
tick 1	ə kʰɪt	EPG patterns confirm perceptual analysis
key 2	ə tʰi	WI alveolar MAG in addition to correct velar contact patterns
shark 2	ə sʃɑ:ɹt	EPG patterns confirm perceptual analysis
beak 2	ə (d) bit	EPG patterns confirm perceptual analysis
kitkat 1	ə tʰɪk̚tækt	EPG patterns confirm perceptual analysis
kitkat (rep 1)	ə tʰɪdkæt	EPG patterns confirm perceptual analysis
kitkat (rep 2)	ə tʰɪdkæt	WI alveolar MAG in addition to correct velar contact patterns
kitkat (rep 3)	ə tʰɪdkæt	EPG patterns confirm perceptual analysis
kitkat (rep 4)	ə tʰɪtkæt	EPG patterns confirm perceptual analysis
kitkat (rep 5)	ə tʰɪdkæt	EPG patterns confirm perceptual analysis
kitkat (rep 7)	ə tʰɪtkæt	WI alveolar MAG in addition to correct velar contact patterns
kitkat (rep 8)	ə tʰɪtkæt	EPG patterns confirm perceptual analysis
kitkat (rep 9)	ə tʰɪtkæt	EPG patterns confirm perceptual analysis
kitkat (rep 10)	ə tʰɪtkæt	EPG patterns confirm perceptual analysis

Table 4: EPG contact patterns for perceived substitutions produced by IE.

Appendix D

Closure durations for "deer"

Repetition	1	2	3	4	5	6	7	8	9	10
FM	0.138	0.168	0.139	0.178	0.179	0.199	0.169	0.238	0.179	0.188
MU	0.299	0.498	0.359	0.179	0.477	0.378	0.339	0.338	0.358	0.326
CR	0.169	0.169	0.069	0.159	0.149	0.179	0.169	0.169	0.199	0.199
JM	0.099	0.11	0.099	0.099	0.089	0.089	0.089	0.099	0.108	0.089
IE	0.159	0.149	0.099	0.158	0.119	0.119	0.119	0.13	0.119	0.119
PW	0.146	0.107	0.107	0.127	0.157	0.127	0.137	0.147	0.127	0.137
FC	0.19	0.259	0.189	0.199	0.218	0.209	0.219	0.299	0.248	0.22
HJ	0.299	0.208	0.019	0.178	0.158	0.199	0.149	0.21	0.21	0.198
HL	0.079	0.04	0.059	0.059	0.08	0.079	0.069	0.049	0.059	0.029
AM	0.1	0.109	0.098	0.117	0.099	0.108	0.109	0.089	0.108	0.1
FG	0.139	0.129	0.15	0.15	0.15	0.16	0.15	0.149	0.169	0.14
JS	0.099	0.11	0.12	0.119	0.12	0.129	0.129	0.109	0.12	0.11
KM	0.109	0.089	0.11	0.1	0.12	0.12	0.089	0.11	0.099	0.11
LD	0.069	0.089	0.089	0.089	0.058	0.089	0.088	0.069	0.068	0.069
LE	0.069	0.079	0.088	0.098	0.099	0.129	0.13	0.139	0.129	0.109
PR	0.109	0.109	0.119	0.11	0.109	0.129	0.139	0.129	0.119	0.119
SN	0.069	0.079	0.069	0.069	0.08	0.07	0.07	0.069	0.06	0.089
WH	0.089	0.089	0.099	0.08	0.07	0.089	0.089	0.1	0.079	0.08
WJ	0.099	0.099	0.109	0.099	0.089	0.099	0.109	0.099	0.08	0.099

Table 1: Durational measures (secs) for /d/ closure over 10 repetitions for "deer".

Closure durations for "kitkat"

Repetition	1	2	3	4	5	6	7	8	9	10
FM	0.168	0.139	0.175	0.147	0.13	0.113	0.154	0.166	0.136	0.164
MU	0.306	0.193	0.249	0.304	0.14	0.127	0.298	0.216	0.187	0.087
CR	0.5	0.2	0.183	0.181	0.129	0.147	0.186	0.177	0.175	0.171
JM	0.099	0.084	0.088	0.107	0.078	0.088	0.098	0.128	0.089	0.088
IE	0.171	0.2	0.178	0.181	0.151	0.143	0.187	0.192	0.15	0.16
PW	0.155	0.156	0.192	0.171	0.182	0.201	0.173	0.185	0.172	0.201
FC	0.24	0.197	0.193	0.237	0.227	0.242	0.232	0.272	0.223	0.242
HJ	0.118	0.15	0.109	0.128	0.091	0.087	0.14	0.141	0.16	0.097
HL	0.155	0.2	0.183	0.318	0.304	0.278	0.363	0.248	0.292	0.182
AM	0.06	0.1	0.09	0.089	0.079	0.098	0.08	0.08	0.09	0.09
FG	0.099	0.109	0.098	0.088	0.1	0.089	0.086	0.066	0.099	0.088
JS	0.059	0.048	0.03	0.039	0.049	0.069	0.018	0.059	0.009	0.069
KM	0.059	0.093	0.069	0.069	0.082	0.079	0.092	0.079	0.096	0.093
LD	0.06	0.059	0.02	0.07	0.02	0.05	0.08	0.08	0.07	0.07
LE	0.08	0.069	0.079	0.07	0.09	0.09	0.059	0.069	0.071	0.091
PR	0.099	0.108	0.099	0.098	0.089	0.088	0.08	0.088	0.089	0.098
SN	0.078	0.089	0.049	0.069	0.048	0.049	0.059	0.029	0.079	0.029
WH	0.119	0.119	0.009	0.118	0.118	0.108	0.118	0.119	0.127	0.099
WJ	0.089	0.088	0.089	0.079	0.089	0.089	0.079	0.09	0.088	0.089

Table 2: Durational measures (secs) for /k/ closure over 10 repetitions for "kitkat".

Test Of Variance for duration of /d/ closure in "deer"

Compare the variance for the duration of stop closure for word "deer" (annotation points 2 to 5) for each aphasic speaker with the control group

$H_0 \quad \sigma_1^2 = \sigma_2^2$

$H_1 \quad \sigma_1^2 \neq \sigma_2^2$

$$F = \frac{S_1^2}{S_2^2} \quad \frac{(\text{standard deviation of group 1})^2}{(\text{standard deviation of group 2})^2}$$

Critical value derived from F table

V1 (dF1) $n_1 - 1 = 9$

V2 (df2) $n_2 - 1 = 99$

Critical values F=1.97 for $\alpha = 0.05$

Reject H_0 if F is greater than or equal to F critical value Subjects

F values for individual aphasic speakers

FM $F = \frac{S_1^2}{S_2^2} = \frac{0.02873^2}{0.0221429^2} = \frac{0.0008254}{0.0004903} = 1.683$ **The H_0 cannot be rejected**
MU $F = \frac{S_1^2}{S_2^2} = \frac{0.08904^2}{0.0221429^2} = \frac{0.0079281}{0.0004903} = 16.17$ **The H_0 can be rejected**
CR $F = \frac{S_1^2}{S_2^2} = \frac{0.03669^2}{0.0221429^2} = \frac{0.0013462}{0.0004903} = 2.746$ **The H_0 can be rejected**
JM $F = \frac{S_1^2}{S_2^2} = \frac{0.00798^2}{0.0221429^2} = \frac{0.0000637}{0.0004903} = 0.130$ **The H_0 cannot be rejected**
IE $F = \frac{S_1^2}{S_2^2} = \frac{0.01983^2}{0.0221429^2} = \frac{0.0003932}{0.0004903} = 0.802$ **The H_0 cannot be rejected**
PW $F = \frac{S_1^2}{S_2^2} = \frac{0.01645^2}{0.02214292} = \frac{0.0002706}{0.0004903} = 0.552$ **The H_0 cannot be rejected**
FC $F = \frac{S_1^2}{S_2^2} = \frac{0.03449^2}{0.0221429^2} = \frac{0.0011896}{0.0004903} = 2.426$ **The H_0 can be rejected**
HJ $F = \frac{S_1^2}{S_2^2} = \frac{0.06036^2}{0.0221429^2} = \frac{0.0036433}{0.0004903} = 7.431$ **The H_0 can be rejected**
HL $F = \frac{S_1^2}{S_2^2} = \frac{0.01724^2}{0.0221429^2} = \frac{0.0002972}{0.0004903} = 0.606$ **The H_0 cannot be rejected**

Table 3: Test of variance for duration of /d/ closure in "deer" for individual aphasic subjects.

F values for aphasic group

Comparison of the aphasic group with the control group where V1 = 89 and V2 = 99

Critical values for 100,100 (nearest to 89,99 in F tables) are:

$\alpha = 0.05$ F critical value at 100,100 = 1.483

$$F = \frac{S_1^2}{S_2^2} = \frac{0.085067^2}{0.0221429^2} = \frac{0.0072364}{0.0004903} = 14.759$$

Can reject $H_0 \quad \sigma_1^2 = \sigma_2^2$ **at** $\alpha = 0.05$

Test Of Variance for duration of the word "deer"

Compare the variance for the duration of the word "deer" (annotation points 2 to 7)

$H_0 \quad \sigma_1^2 = \sigma_2^2$

$H_1 \quad \sigma_1^2 \neq \sigma_2^2$

$$F = \frac{S_1^2}{S_2^2} \quad \frac{(\text{standard deviation of group 1})^2}{(\text{standard deviation of group 2})^2}$$

Critical value derived from F table

V1 (df1) $n_1 - 1 = 9$

V2 (df2) $n_2 - 1 = 99$

Critical values F=1.97 for $\alpha = 0.05$

Reject H_0 if F is greater than or equal to F critical value where F= calculated statistic.

F values for individual aphasic speakers

FM $F = \frac{S_1^2}{S_2^2} = \frac{0.05811^2}{0.065317523^2} = \frac{0.0033768}{0.0042664} = 0.791$ **The H_0 cannot be rejected**
MU $F = \frac{S_1^2}{S_2^2} = \frac{0.10510^2}{0.065317523^2} = \frac{0.011046}{0.0042664} = 2.589$ **The H_0 can be rejected**
CR $F = \frac{S_1^2}{S_2^2} = \frac{0.07164^2}{0.065317523^2} = \frac{0.0051323}{0.0042664} = 1.203$ **The H_0 can be rejected**
JM $F = \frac{S_1^2}{S_2^2} = \frac{0.07941^2}{0.065317523^2} = \frac{0.0063059}{0.0042664} = 1.478$ **The H_0 can be rejected**
IE $F = \frac{S_1^2}{S_2^2} = \frac{0.03984^2}{0.065317523^2} = \frac{0.0015872}{0.0042664} = 0.372$ **The H_0 cannot be rejected**
PW $F = \frac{S_1^2}{S_2^2} = \frac{0.02106^2}{0.065317523^2} = \frac{0.0004435}{0.0042664} = 0.104$ **The H_0 cannot be rejected**
FC $F = \frac{S_1^2}{S_2^2} = \frac{0.04104^2}{0.065317523^2} = \frac{0.0000263}{0.0042664} = 0.006$ **The H_0 cannot be rejected**
HJ $F = \frac{S_1^2}{S_2^2} = \frac{0.02789^2}{0.065317523^2} = \frac{0.0007779}{0.0042664} = 0.182$ **The H_0 cannot be rejected**
HL $F = \frac{S_1^2}{S_2^2} = \frac{0.03766^2}{0.065317523^2} = \frac{0.0014183}{0.0042664} = 0.332$ **The H_0 cannot be rejected**

Table 4: Test of variance for duration of the word "deer" for individual aphasic subjects.

F values for aphasic group

Comparison of the aphasic group with the control group where V1 = 89 and V2 = 99 for duration of word "deer" annotation points 2 to 7.

Critical values for 100,100 (nearest to 89,99 in F tables) are:

$\alpha = 0.05$ F critical value at 100,100 = 1.483

$$F = \frac{S_1^2}{S_2^2} = \frac{0.1273381682^2}{0.065317523^2} = \frac{0.0162261}{0.0042664} = 3.803$$

The H_0 can be rejected $H_1 \quad \sigma_1^2 \neq \sigma_2^2$

Test Of Proportions

H_0: $p_1 = p_2$ H_1: $p_1 \neq p_2$

Where p_1 = aphasic subject p_2 = control group

Significance level $\alpha = 0.05$ $Z\,\alpha$ for 0.05 (two tail) = 1.96

If Z value is equal to or greater than critical value then reject H_0

Equation

$$Z = \frac{|\hat{p}_1 - \hat{p}_2| - \frac{1}{2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}{\sqrt{\bar{p}(1-\bar{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Z values for individual aphasic speakers

FM

FM $(\hat{p}_1) = 0.2902$ Controls $(\hat{p}_2) = 0.2181$ Overall $(\overline{p}) = 0.25415$

$$Z = \frac{|0.2902 - 0.2181| - \frac{1}{2}\left(\frac{1}{10} + \frac{1}{100}\right)}{\sqrt{0.25415(1 - 0.25415)\left(\frac{1}{10} + \frac{1}{100}\right)}} \qquad Z = \frac{0.0171}{0.102} \qquad Z = 0.168$$

Cannot reject H_0

MU

MU $(\hat{p}_1) = 0.4231$ Controls $(\hat{p}_2) = 0.2181$ Overall $(\overline{p}) = 0.3206$

$$Z = \frac{|0.4231 - 0.2181| - \frac{1}{2}\left(\frac{1}{10} + \frac{1}{100}\right)}{\sqrt{0.3206(1 - 0.3206)\left(\frac{1}{10} + \frac{1}{100}\right)}} \qquad Z = \frac{0.15}{0.109} \qquad Z = 1.376$$

Cannot reject H_0

CR

CR $(\hat{p}_1) = 0.2352$ Controls $(\hat{p}_2) = 0.2181$ Overall $(\overline{p}) = 0.22664$

$$Z = \frac{|0.2352 - 0.2181| - \frac{1}{2}\left(\frac{1}{10} + \frac{1}{100}\right)}{\sqrt{0.22664(1 - 0.22664)\left(\frac{1}{10} + \frac{1}{100}\right)}} \qquad Z = \frac{0.0171 - 0.055}{0.0982} \qquad Z = -0.386$$

Cannot reject H_0

JM

JM $(\hat{p}_1) = 0.1463$ Controls $(\hat{p}_2) = 0.2181$ Overall $(\overline{p}) = 0.1822$

$$Z = \frac{|0.1463 - 0.2181| - \frac{1}{2}\left(\frac{1}{10} + \frac{1}{100}\right)}{\sqrt{0.1822(1 - 0.1822)\left(\frac{1}{10} + \frac{1}{100}\right)}} \qquad Z = \frac{0.0168}{0.091} \qquad Z = 0.185$$

Cannot reject H_0

IE

IE $(\hat{p}_1) = 0.2693$ Controls $(\hat{p}_2) = 0.2181$ Overall $(\overline{p}) = 0.2437$

$$Z = \frac{|0.2693 - 0.2181| - \frac{1}{2}\left(\frac{1}{10} + \frac{1}{100}\right)}{\sqrt{0.2437(1 - 0.2437)\left(\frac{1}{10} + \frac{1}{100}\right)}} \qquad Z = \frac{-0.2593}{0.1007} \qquad Z = -2.575$$

Reject the H_0

PW

PW $(\hat{p}_1) = 0.2241$ Controls $(\hat{p}_2) = 0.2181$ Overall $(\overline{p}) = 0.2211$

$$Z = \frac{|0.2241 - 0.2181| - \frac{1}{2}\left(\frac{1}{10} + \frac{1}{100}\right)}{\sqrt{0.2211(1 - 0.2211)\left(\frac{1}{10} + \frac{1}{100}\right)}} \qquad Z = \frac{-0.049}{0.0973} \qquad Z = 0.504$$

Cannot reject H_0

FC

FC $(\hat{p}_1) = 0.3782$ Controls $(\hat{p}_2) = 0.2181$ Overall $(\overline{p}) = 0.29815$

$$Z = \frac{|0.3782 - 0.2181| - \frac{1}{2}\left(\frac{1}{10} + \frac{1}{100}\right)}{\sqrt{0.29815(1 - 0.29815)\left(\frac{1}{10} + \frac{1}{100}\right)}} \qquad Z = \frac{0.1051}{\sqrt{0.0115}} \qquad Z = 0.979$$

Cannot reject H_0

HJ HJ $(\hat{p}_1) = 0.2604$ Controls $(\hat{p}_2) = 0.2181$ Overall $(\bar{p}) = 0.23925$ $Z = \dfrac{\lvert 0.2604 - 0.2181\rvert - \frac{1}{2}\left(\frac{1}{10}+\frac{1}{100}\right)}{\sqrt{0.23925(1-0.23925)\left(\frac{1}{10}+\frac{1}{100}\right)}}$ $Z = \dfrac{-0.0127}{0.1}$ $Z = -0.127$ **Cannot reject** H_0
HL HL $(\hat{p}_1) = 0.1511$ Controls $(\hat{p}_2) = 0.2181$ Overall $(\bar{p}) = 0.1846$ $Z = \dfrac{\lvert 0.1511 - 0.2181\rvert - \frac{1}{2}\left(\frac{1}{10}+\frac{1}{100}\right)}{\sqrt{0.1846(1-0.1846)\left(\frac{1}{10}+\frac{1}{100}\right)}}$ $Z = \dfrac{0.0743}{0.1863}$ $Z = 0.399$ **Cannot reject** H_0

Table 5: Test of proportions for individual aphasic subjects.

Z values for aphasic group

Aphasics $(\hat{p}_1) = 0.2642$ Controls $(\hat{p}_2) = 0.2181$ Overall $(\bar{p}) = 0.24115$

$$Z = \frac{\lvert 0.2642 - 0.2181\rvert - \frac{1}{2}\left(\frac{1}{10}+\frac{1}{100}\right)}{\sqrt{0.24115(1-0.24115)\left(\frac{1}{10}+\frac{1}{100}\right)}} \qquad Z = \frac{-0.0089}{0.1003} \qquad Z = 0.089$$

Cannot reject H_0

Test Of Variance for duration of /k/ closure in "kitkat"

Compare the variance for the duration of stop closure for word "kitkat" (annotation points 2 to 3) for each aphasic speaker with the control group

$H_0 \quad \sigma_1^2 = \sigma_2^2$

$H_1 \quad \sigma_1^2 \neq \sigma_2^2$

$$F = \frac{S_1^2}{S_2^2} \quad \frac{(\text{standard deviation of group 1})^2}{(\text{standard deviation of group 2})^2}$$

Critical value derived from F table

V1 (df1) $n_1 - 1 = 9$

V2 (df2) $n_2 - 1 = 99$

Critical values F=1.97 for $\alpha = 0.05$

Reject H_0 if F is greater than or equal to F critical value where F= calculated statistic.

F values for individual aphasic speakers

FM $F=\frac{S_1^2}{S_2^2}\quad=\frac{0.01977^2}{0.020994^2}\quad=\frac{0.0003909}{0.0004407}\quad=0.887$ **The H_0 cannot be rejected at α = 0.01**
MU MU $F=\frac{S_1^2}{S_2^2}\quad=\frac{0.07712^2}{0.020994^2}\quad=\frac{0.0059475}{0.0004407}\quad=13.5$ **The H_0 can be rejected at α = 0.01**
CR $F=\frac{S_1^2}{S_2^2}\quad=\frac{0.10551^2}{0.020994^2}\quad=\frac{0.0111324}{0.0004407}\quad=25.26$ **The H_0 can be rejected at α = 0.01**
JM $F=\frac{S_1^2}{S_2^2}\quad=\frac{0.01439^2}{0.020994^2}\quad=\frac{0.0002071}{0.0004407}\quad=0.470$ **The H_0 cannot be rejected at α = 0.01**
IE $F=\frac{S_1^2}{S_2^2}\quad=\frac{0.01969^2}{0.020994^2}\quad=\frac{0.0003877}{0.0004407}\quad=0.880$ **The H_0 cannot be rejected at α = 0.01**
PW PW $F=\frac{S_1^2}{S_2^2}\quad=\frac{0.01638^2}{0.020994^2}\quad=\frac{0.0002683}{0.0004407}\quad=0.609$ **The H_0 cannot be rejected at α = 0.01**
FC $F=\frac{S_1^2}{S_2^2}\quad=\frac{0.02295^2}{0.020994^2}\quad=\frac{0.0005267}{0.0004407}\quad=1.195$ **The H_0 cannot be rejected at α = 0.01**
HJ $F=\frac{S_1^2}{S_2^2}\quad=\frac{0.02586^2}{0.020994^2}\quad=\frac{0.0006687}{0.0004407}\quad=1.517$ **The H_0 cannot be rejected at α = 0.01**
HL $F=\frac{S_1^2}{S_2^2}\quad=\frac{0.06959^2}{0.020994^2}\quad=\frac{0.0048428}{0.0004407}\quad=10.989$ **The H_0 can be rejected at α = 0.01**

Table 6: Test of variance for duration of /k/ closure in "kitkat" for individual aphasic speakers.

F values for aphasic group

Comparison of the aphasic group with the control group for duration of /k/ closure in "kitkat", where V1 = 89 and V2 = 99

Critical values for 100,100 (nearest to 89,99 in F tables) are:

$\alpha = 0.05$ F critical value at 100,100 = 1.483

$$F=\frac{S_1^2}{S_2^2}\quad=\frac{0.0513^2}{0.020994^2}\quad=\frac{0.0026317}{0.0004407}\quad=5.972$$

The H_0 can be rejected at α = 0.05

$H_1 \quad \sigma_1^2 \neq \sigma_2^2$

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